NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A CONSIDERATION OF FACTORS CONTRIBUTING
TO STRENGTH DIFFERENCES
IN MEN AND WOMEN

by

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June 1979

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The present effort discusses how the different physiological/anatomical characteristics of the sexes form a basis

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With an understanding of the strength capabilities of men and women and a comprehensive understnading of job requirements, the effective and efficient utilization of both sexes may be achieved.

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A Consideration of Factors Contributing To Strength Differences in Men and Women

by

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Submitted in partial fulfillment of the
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ABSTRACT

The expansion of opportunities for women in today's military has increased the importance of understanding how and why men and women differ in strength, stamina, and work capacity.

The present effort discusses how the different physiological/anatomical characteristics of the sexes form a basis for physical strength differences. Other factors, such as age, stature, weight, cultural influences, biomechanics, and training contribute to the significant differences in physical strength capabilities which are demonstrated both as to scope and degree.

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I. INTRODUCTION

The objective of this paper is to provide a general understanding, in clear non-technical terms, of the physical strength differences which exist between men and women and how these differences affect their capacity for performing work.

Because these physical strength differences have a basis in the physiological/anatomical make up of each sex, a significant portion of this paper has been devoted to developing an understanding of the physiological differences between the sexes which contribute to physical strength differences.

No detailed knowledge of human physiology is required prior to reading this paper.

II. THE DEMAND FOR WOMEN

The role of women in society has been undergoing change since well before the time of Christ,[1] but the past decade has seen, perhaps, the greatest changes per unit time ever. The women's liberation movement, in all of its varied forms, has provided a force in society which has brought about (in both men and women) a re-evaluation and re-definition of sex roles in almost every walk of life.

Women are now entering into many occupational fields formerly closed to them by law, tradition, and/or sexist bigotry. Many of these transitions are readily visible in everyday life in that women can be seen employed in law enforcement, the trucking industry, electric and telephone line repair crews, and on road construction gangs.

The American military has not been exempt from this social upheaval and blurring of traditional sex roles. Even though there have been reports of women fighting alongside men in the American military dating back to the Revolutionary War (e.g. "Molly Pitcher"), their usual military roles until recently have been in the more traditional fields of health care, administration and communications.[2] Several different factors converged in the seventies to radically change the situation of women within the military.

First, the elimination of the draft in 1973 removed many incentives for males to volunteer for duty in the armed forces. Compounding the problem of acquiring enough men were the

services' attempts to upgrade the quality of personnel allowed to enlist by limiting the number of non high school graduates and category IV high school graduates (those scoring in the 10th-30th percentile on the service administered mental aptitude tests).

Second, projections from the Bureau of Census[3] for 18 year old American men and women show a decline of 15.1% between July 1975 and July 1985. Attributed in part to the passing of the post World War II "baby boom" and to current birth control practices, this problem of a shrinking pool of military aged (17-21) population further aggravates the personnel supply problems for the military.

Third, the military presents special opportunities for women which the civilian sector of society does not. On the average, men and women who join the military are promoted at the same rate,[4] although advancement of women in the highest officer ranks is still restricted, both by law and tradition.

Pay scales comparing mean annual earnings of civilians and military, taken from Binkin and Bach's Women in the Military,[5] are shown in Figure 1.

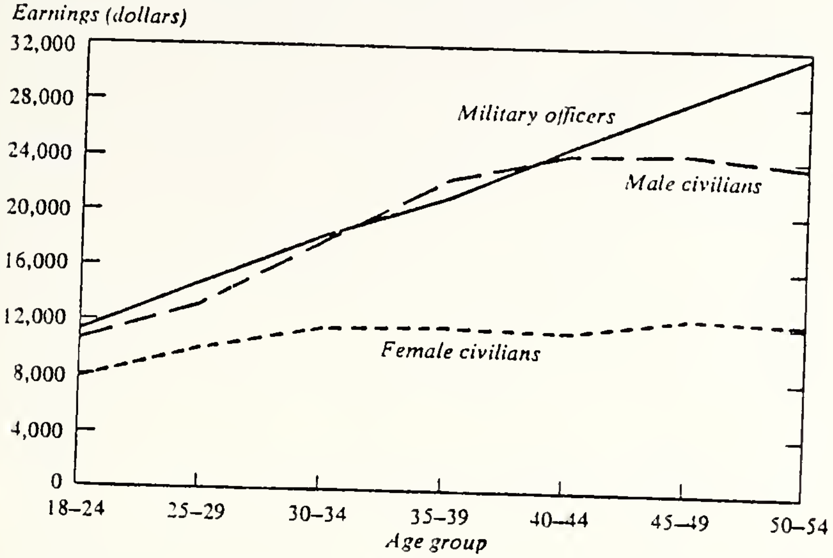
This comparison shows in every instance that female civilians (by age group) earn less than their male and military counterparts. Where a male civilian, with less than 4 years college, in the 25-29 age groups earned approximately $11,000 in 1975, comparable women in the civilian sector earned approximately $7,000 or roughly 64% of their male counterparts. In

the military enlisted sector (where men and women have equal pay scales) a women with the same characterics of the man mentioned above could have earned approximately $9,000 a year which equates to roughly 29% more than her civilian counterpart.

A combination of the factors of: (1) increased difficulty in enlisting available young males, (2) a decreasing 18-21 year old population, and (3) greater opportunities for women with the expansion of women's roles in society, results in a greater demand for women in the military. The desirability of using more women increases when the various costs of recruiting are examined. The average cost of recruiting a male high school graduate who scores at least average on entrance tests is $2,142 as compared to the cost of $150 for a woman of equivalent mental capability or for a young male non-high school graduate.[6]

The fact that women are a valuable resource to the military cannot be denied. How women are utilized within the military is important not only to the military commanders concerned with unit effectiveness, but to the women, as well as the men, who serve in these units. There are many tasks that women can perform as well, if not better, than their male counterparts. There are also many tasks within the military which men feel women cannot perform because of the "obvious physical strength differences" which exist between the sexes. Concerning these "obvious physical strength differences," there are several different schools of thought. One school of thought (that

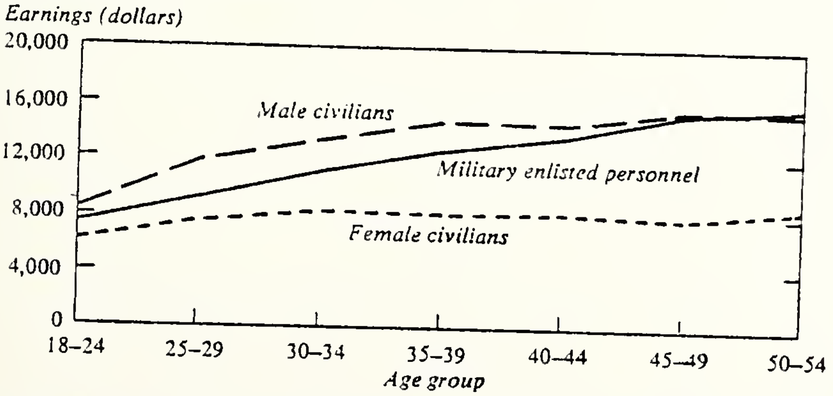
Comparison of Mean Annual Earnings of Civilians with College Education, by Sex and Age, and Commissioned Officers, by Age, 1975[a]



Sources: Military earnings—basic pay, quarters and subsistence allowance, and the tax advantages that accrue because allowances are not taxable—based on unpublished data provided by the Office of the Assistant Secretary of Defense for Manpower and Reserve Affairs, October 1975; civilian earnings based on unpublished data provided by the U.S. Department of Commerce, Bureau of the Census, November 1976.

a. Civilians employed full time with four or more years of college. It should be noted that too much emphasis should not be attached to the divergence beyond the 40–44 age group in annual earnings between military officers and male civilians. There are relatively few military officers beyond that age group and they are generally in high-ranking positions analogous to executives in the private sector.

Comparison of Mean Annual Earnings of Civilians by Sex and Age, and Military Enlisted Personnel, by Age, 1975[a]



a. Civilians employed full time with at least four years of high school but less than four years of college.

(From: Binkin, M. and Bach, S., Women and the Military, Brookings, Washington, D.C., 1977, p. 32.)

Figure 1

of the superior man - inferior woman) is that women are physically inferior to men, and no amount of training will ever elevate women to equal men physically.[7] Another school of thought (one held by the more radical feminist groups) is that women are inherently superior to men in all things.[8] They reason that young women are not as physically strong as young men because a sexist society holds back young girls from the physical opportunities given young boys, and if both had equal opportunities, women's abilities would far exceed those of men. A third, and more moderate school of thought, is held by the equalitarians.[9] They hold that men and women are, more or less, equal in all things and if equal physical opportunities were made available to young girls, sex differences in strength and stamina would disappear.

III. AN OVERVIEW OF EXERCISE PHYSIOLOGY

To answer the important questions concerning whether any sex differences in strength and stamina actually exist an understanding of how the human body performs physical activities is necessary.

Up to a certain point, an analogy can be drawn between the human body and an internal combustion engine. Just as the motor in an automobile uses fuel and oxygen in a process which produces energy, heat, and waste products (exhaust) the human body uses fuel (food) and oxygen and likewise produces energy, heat and waste products. Just as the automobile engine requires some sort of cooling so does the human body. And much like larger engines producing more power and consuming more fuel, larger human bodies generally have a larger energy intake and power output than do smaller bodies.

Muscles make up approximately 45% of the weight of the human body. There are basically two types of muscles (1) voluntary and (2) involuntary.[10] Voluntary muscles are those which can consciously be controlled at will such as those used to bend an arm or stretch a leg. Involuntary muscles are not generally under conscious control and are found in the walls of blood vessels, intestines, the badder and so on.

Muscle is composed of approximately 75% water, 20% protein and 5% minerals and organic compounds. The main minerals are potasium, magnesium, sodium, phosphorus and calcium. The organic compounds are glycogen, glucose and certain hormones

of the adrenal cortex. The functional unit within each muscle is the muscle fiber. Muscle fiber is an elongated cell varying in length but generally between .5 and 14 centimeters (cm) long.[11] Each fiber is located close to a capillary thereby facilitating the exchange between the fiber and the blood. A muscle can contain anywhere from 100,000 to 1,000,000 fibers, which are sometimes connected in series.

The importance of muscle tissue lies in its ability to contract to about one half of its full normal length. It is this contraction which enables the limbs of the body to move and perform actual work. The potential for the amount of work a muscle can perform is therefore proportional to its fully extended length.

Each individual muscle fiber contracts with a certain force. The contraction of the muscle fibers is additive and proportional to the muscle's cross-sectional area. The maximum muscular force in humans is approximately 4 kilograms (kg) per square cm of cross-sectional area of the muscle.[12] The greatest force exerted by the muscle is at the beginning of the contraction and decreases as the muscle shortens.

Muscle fiber contraction is stimulated by incoming electrical nerve impulses.[13] These impulses cause a series of chemical reactions within the fiber, altering the properties of the protein molecules causing their positions to change thereby shortening the muscle fiber. The chemical reactions use the glycogen stored in the fibers as a source of energy. The glucose (of which the glycogen is composed) breaks down

into lactic acid in an anaerobic process (anaerobic processes are those in which oxygen is not consumed as opposed to aerobic processes which do involve the consumption of oxygen) and releases energy for the fiber contraction. Eighty percent of this lactic acid is reconverted back into glucose in an aerobic process which also generates heat.[14]

In these two chemical processes, the importance of glucose as a source of energy for muscular work is manifest.

Oxygen is required for the reconversion of most of the lactic acid back into glucose, and because of this, oxygen is the second most important factor in muscular activity. The remaining waste products of the other chemical reactions and the remaining lactic acid are carried away from the muscle tissue by venous blood, where it is further broken down in the liver and re-released into the blood stream as glucose. If enough oxygen is not available for its reconversion back to glucose, the lactic acid accumulates and muscle action declines and stops. This sequence of events is shown in Figure 2.

During the bare minimal level (basal metabolic rate) and resting levels of metabolic activity enough oxygen is available to sustain muscle cellular activity. As the metabolic activity increases however, oxygen is consumed at a rapid rate, lowering the oxygen concentration within the cells. Oxygen in the blood then dissociates from the hemoglobin and, through osmosis, passes through the cellular wall into the muscle tissue. There is, however, a time lag between the onset of muscular action

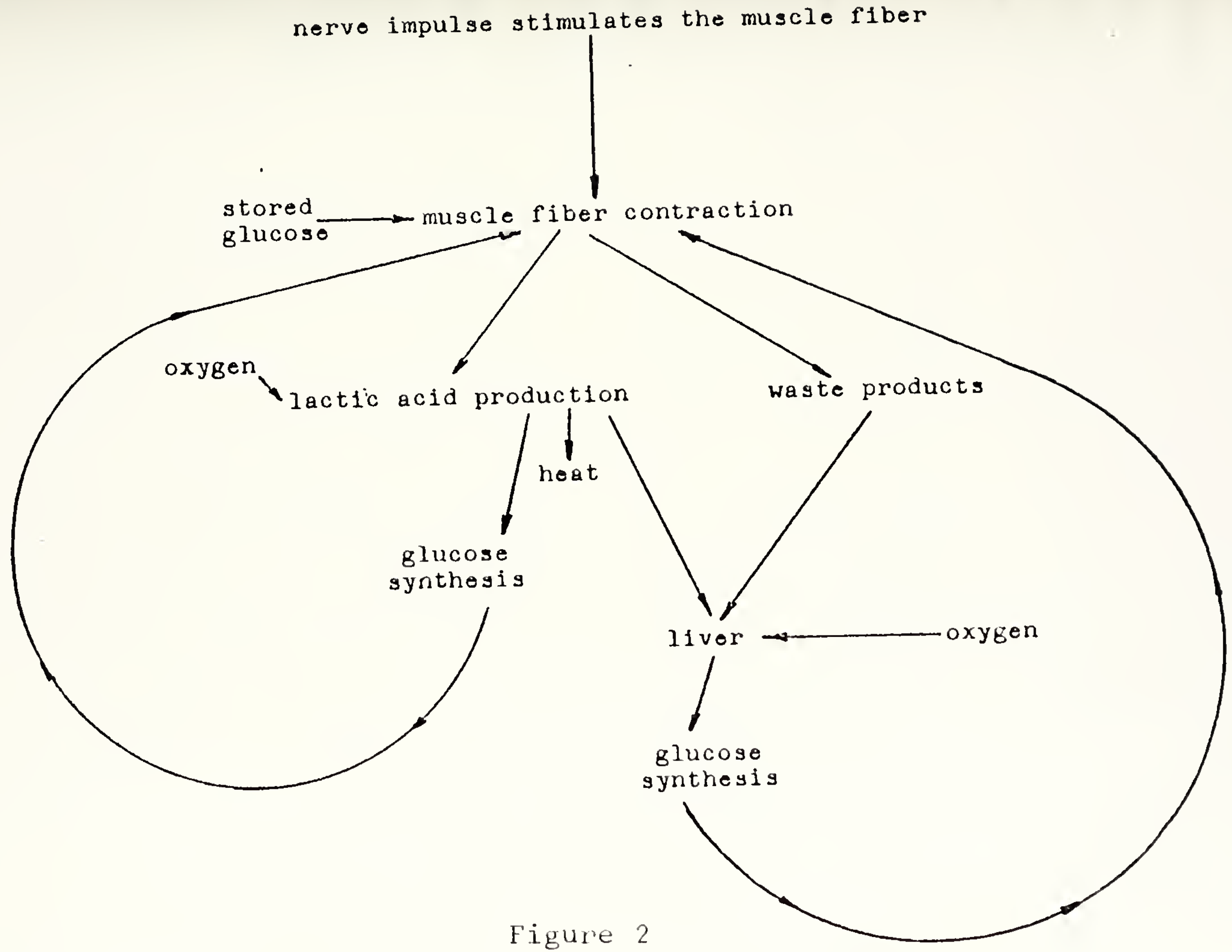


Figure 2

Factors in muscle contraction.

and the increase of oxygen demanded. Since an active muscle requires more than a twentyfold increase in the supply of oxygen, the flow of blood must be increased correspondingly. This is where the anaerobic process breaking down glucose into lactic acid and releasing energy allows the muscles to function until the blood has time to increase flow to meet the higher oxygen demand.

Glucose, like oxygen, is stored in limited supply within the muscle cell; as the level of muscular activity increases, these energy stores are soon depleted. Additional glucose is then released into the blood stream from the liver, where it had been stored as a product of digestion and lactic acid conversion. The blood, then, carries glucose as well as oxygen to muscle tissue.

Muscles actually help the heart in increasing the flow of blood. To understand this it must be realized that there are two types of muscular activity: (1) dynamic (isotonic) and (2) static (isometric). In dynamic work, the muscles increase in tension, shorten and then relax in a periodic manner. In static work, muscles tense up with little actual shortening thereby exerting a force. The force continues to be exerted as long as the muscle remains in a tensed state.

Examples of each type of work would be running (dynamic) and holding a fairly heavy object at arms length or pushing on a wall (static). During static activity, the blood supply to the muscle is reduced in proportion to the force of contraction. When the applied force becomes equal to

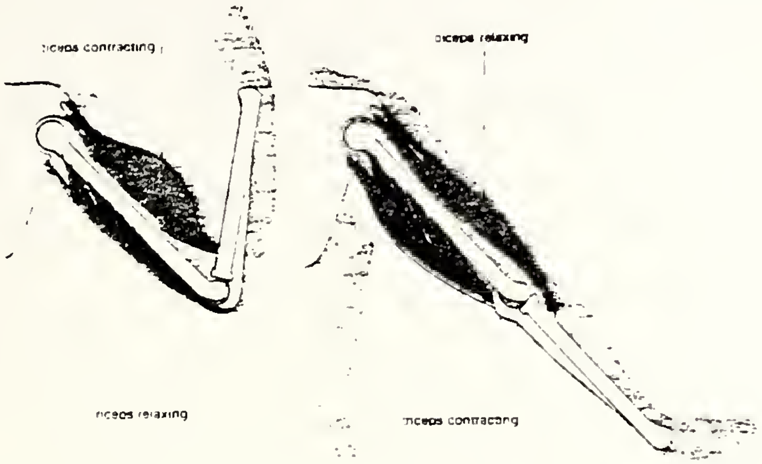
approximately 60% of the maximum force of the muscle, the supply of blood is completely stopped. In this case the blood vessels are compressed by an increase in the pressure within the muscle until they can flow no more. In dynamic work, however, the periodic increase and decrease in tension actually works like a pump. The contraction expels blood and the following relaxation of the muscle tends to draw in blood. In this manner the blood circulation is increased and the muscles receive up to 20 times as much blood during dynamic work than during static work.

Because the flow of blood is decreased during static muscular activity, it is often referred to as a partial or full anaerobic process. Static work is much less efficient than dynamic work tending to consume more energy per given effort than dynamic activities.[15] In addition, fatigue sets in much sooner, perhaps due to the reduced supply of oxygen and increased build up of lactic acid and becomes painful until the muscle is allowed to return to its relaxed state. A high correlation (r=.8) has been found between dynamic and static strength.[16] A fact which greatly facilitates strength testing.

It has been explained how muscles contract and why they need fuel and oxygen. But the mere fact of muscle contraction by itself is not enough to accomplish real physical work. Work is performed by means of levers using the skeletal system of the body with muscles supplying the required power. In discussing muscle power only voluntary muscles will be considered.

A lever is really a mechanical device which produces a rotary motion about an axis or fulcrum.

Figure 3 is an example of such a system of levers.



The arm as a system of levers.
(From: Edholm, O.G., The Biology of Work, McGraw-Hill, New York, 1967, p. 24.)

Figure 3

All muscles are attached at each end by tendons to bones of the skeleton, with one or more skeletal joints in between the points of attachment. When the biceps muscle of the arm contracts, as shown in Figure 3, the two endpoints (points of attachment) of the muscle are brought closer together, thereby raising the arm. The triceps are relaxed in this activity and even extend somewhat performing no work. To straighten the arm, the triceps contract while the biceps relax. This dual action, along with the elasticity of the

tendons, allows for a greater degree of control and prevents jerky motion. For the most part, all movement involves two or more voluntary muscles acting together in this manner.

Several forces are at work in all levers. The effort force (which is applied to overcome inertia and cause motion) is applied to cause rotation in a direction opposite to that of the resistant force. The amount of force required to overcome the resistant force and cause desired movement is dependent on the length of the force arm as compared to the length of the resistance arm. In Figure 3 the force arm is the distance from the fulcrum (elbow) to the point where the effort force is applied. The resistance arm is the distance from the point of application of the resistant force to the end of the lever in a direction away from where the force is applied (from the elbow to the hand).

Since it is generally agreed that it is the nature of the task being performed along with the degree of training, experience, and motivation a person has which really determines how well it is performed, the more strenuous activities would seem to be a logical place to look for sex differences in physical strength.

IV. PHYSIOLOGICAL SEX DIFFERENCES

Since muscular activity depends strongly on fuel (sugars and oxygen), and how efficiently it is consumed, it would seem that the consumption of energy during strenuous activities is a major factor which could tend to limit performance.[17]

Reviewing how energy is used in the body, any difference between men and women in the utilization or delivery of oxygen or glucose to the muscles would have an effect on their physical performance.

Vital Capacity. The vital capacity of the lungs is the maximum amount of air which can be expelled after the greatest possible inhalation of air, and bears an important relationship to a person's physical fitness. Vital capacity is related to body weight and surface area. It has been shown that the ratio of vital capacity to skin surface area is greatest in athletes and least in sedentary women.[18]

Vital capacity, in relation to height, averages 25 cubic centimeters per centimeter of height for men and 20 cubic centimeters per centimeter of height for women. The average vital capacity relative to body surface area is 2500 cubic centimeters per square meter of body surface area for men and 2000 cubic centimeters per square meter for women.[19]

It should be noted, however, that the entire volume of air contained in the vital capacity is not available to the lungs for the gaseous exchange of oxygen.[20] Even when the respiratory muscles of the body are relaxed, air is left in

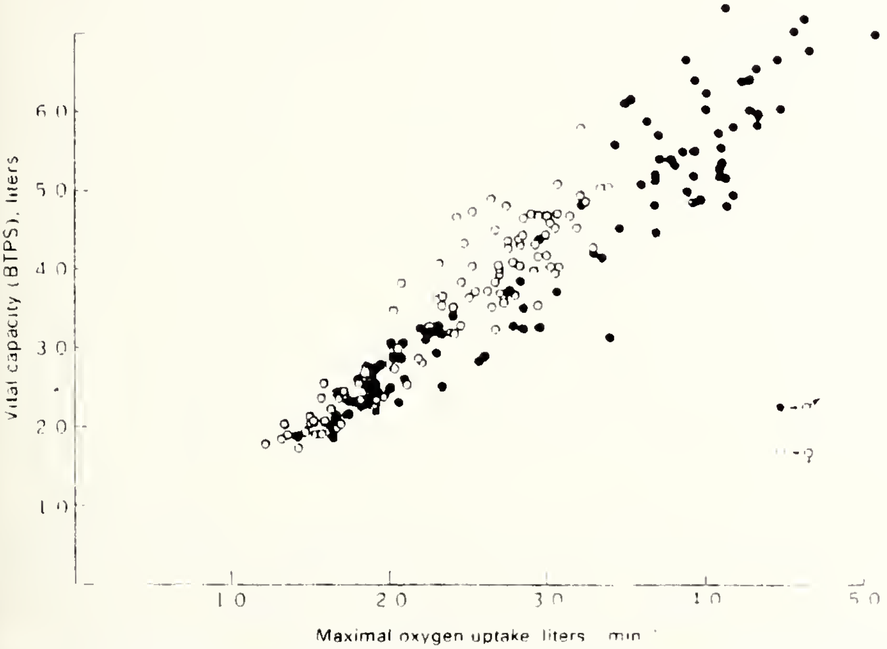
the lungs (the functional residual capacity). A forced maximal exhalation of air at this point expells the expiratory reserve volume, but still leaves some air in the lungs (the residual volume). With the respiratory muscles in a relaxed state, the amount of air pulled in by a maximal inhalation is called the inspiratory reserve volume. The volume of air contained in the lungs at this point is the total lung capacity and, as stated earlier, the maximum amount of air which can now be expelled from the lungs is what is known as the vital capacity. The volume of air which is moved during each respiratory cycle is the tidal volume. The vital capacity, then, consists of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume. The following data are taken from fairly physically fit college physical education students averaging 25 years of age.[21]

	Men	Women
number of subjects	45	51
functional residual capacity	3.4 liters	2.6 liters
total lung capacity	7.2 "	5.4 "
residual volume	1.5 "	1.15 "
vital capacity	5.7 "	4.25 "

In another study, vital capacities compared with the maximal oxygen uptakes (the maximum amount of oxygen which is capable of being consumed by the body during strenuous exercise at sea level) for a group of men and women revealed a high correlation between vital capacity and maximal oxygen

uptake with the highest for both being possessed by men.[22] This is reflected in Figure 4 and is taken from that study.

Another study mentioned in M. Ayoub, C. Grasley and N. Bethea's, Classification, Summary, Relevance and Application of Male/Female Differences in Performances, concerning vital capacities in 17 women cadets at the Air Force Academy,[23] showed the women's vital capacities to be only 8% less than their male counterparts as opposed to 15 - 20% which has typically been found between the mean values of men and women.



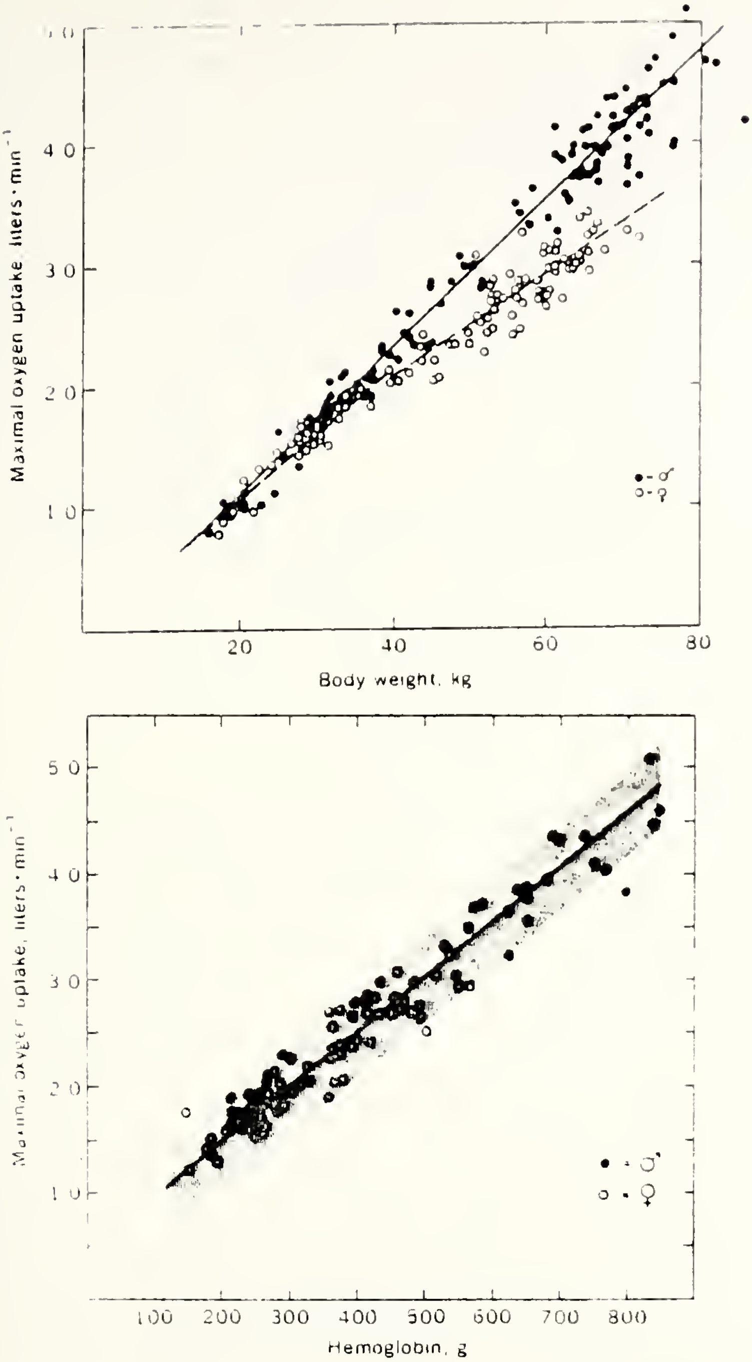
Individual data on vital capacity measured in standing position in relation to maximal oxygen uptake during running or cycling in 190 subjects from seven to thirty years of age *(From P.-O. Åstrand, 1952.)*

(From: Astrand, P.O. and Rodahl, K., Textbook of Work Physiology, McGraw-Hill, New York, 1977, p. 225)

Figure 4

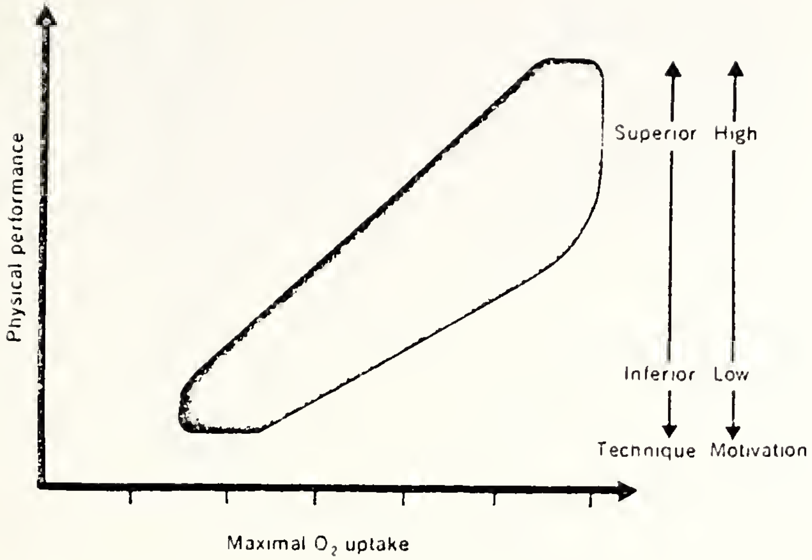
Hemoglobin. The ability of the blood to carry oxygen to the muscles also has a definite affect on work capacity. Approximately 99% of the oxygen carried in the blood is in chemical combination with the hemoglobin of the red blood corpuscles. The amounts of hemoglobin per cubic centimenter (cc) are different, on average, between men and women. Men's hemoglobin per 100 cc of blood is approximately 14.7 grams, and women's is approximately 13.7 grams per 100 cc, or roughly 93% that of men. One gram of hemoglobin is saturated by 1.34 cc of oxygen, therefore men's blood can transport, on average, 19.7 cc of oxygen per 100 cc of blood as compared to 18.4 cc, on average, for women. Astrand[24] uses this difference, along with women's higher content of adipose (fatty) tissue to explain the differences in maximal oxygen uptake between men and women of the same size. When the quantity of hemoglobin is related to the maximal oxygen uptake, the regression lines in Figure 5 become so close to each other as to be insignificantly different.

Aerobic Power. The maximal oxygen uptake (or maximal aerobic power) being the highest uptake an individual can attain during physical exercise (corrected to sea level), is important in physical activities where large muscle groups are used for periods greater than one minute. The relationship between physical performance and the maximal oxygen uptake are shown in Figure 6.



(From Astrand and Rodahl, p. 380.)

Figure 5

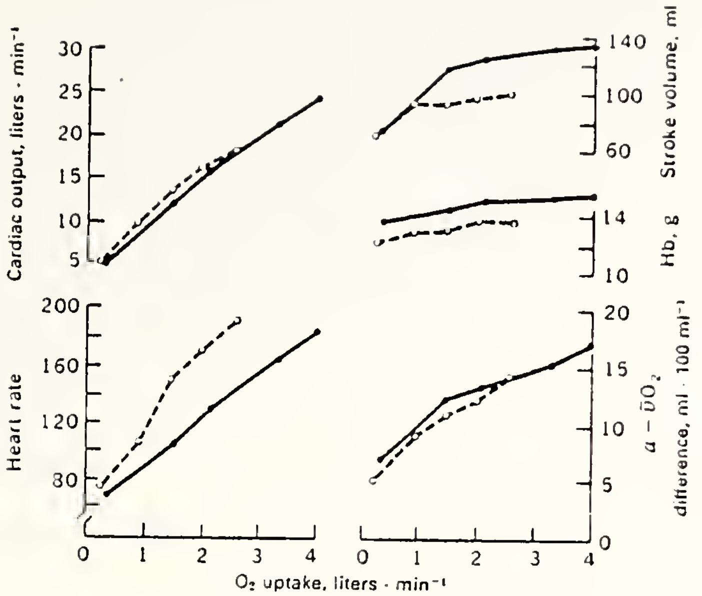


(From: Astrand and Rodahl, p. 320.)

Figure 6

Heart. In order to push the oxygen rich blood to the muscles, the heart rate must be increased. Related to the increased heart rate is the stroke volume, or the amount of blood pumped during each beat of the heart, which increases as well. Women non-athletes generally have a lower stroke volume than men non-athletes[25] and smaller hearts, even when corrections are made for body size.[26] Women, then, would have a faster heart rate than men if performing a task requiring the same energy expenditure. This is shown in Figure 7.

Cooling. Earlier, in the analogy comparing the human body with an internal combustion engine, it was mentioned that the body, like the car engine, requires a cooling system. Heat is produced during the metabolic process and increases



	Age	Height	Weight	Plasma volume	Heart volume
○ ♀	21 yrs	169 cm	62.7 kg	2.87 liters	640 ml
● ♂	24 yrs	179 cm	74.7 kg	3.70 liters	880 ml

The figure is based on average values from measurements on 11 women and 12 men, all of them relatively well trained and working on a bicycle ergometer in the sitting position (P.-O. Astrand et al., 1964.)
(Since the abcissa gives the oxygen uptake in absolute values, the calculated mean curves can be misleading. The less fit subjects have both a low maximal oxygen uptake and low stroke volume. Those with a high capacity for oxygen uptake also have a larger stroke volume. A man with a maximal aerobic power of 5 liters · min^{-1} eventually attains maximal stroke volume first at a work load giving an oxygen uptake of 2 liters · min^{-1}. The one with a maximal oxygen uptake of 3.5 liters · min^{-1} reaches his plateau for stroke volume when the oxygen uptake exceeds 1.3 liters · min^{-1})

(From: Astrand and Rodahl, p. 198)

Figure 7

rapidly as muscular activity increases. Since the mechanical efficiency of the body is only about 25%, 75% of the total energy consumed is converted to heat.[27] This heat is maintained within physiological limits by the process of sweating which

depends on total surface area of the body and the density (the number per square inch) of the sweat glands. Although women have more sweat glands per unit area of body surface than men, women tend to sweat less than men[28] and begin to sweat at higher skin temperatures than men.[29] The problem this presents in terms of a limitation on work capacity is that as temporary heat imbalances occur in the body, blood is routed from the mission of carrying food and oxygen to the muscles and is directed to the body surface where the heated blood can be cooled much the same as the radiator in a car engine cools the water system.[30] In doing this, less fuel is made available to the muscle tissue and fatigue begins to set in earlier as a result of the increase in temperature.

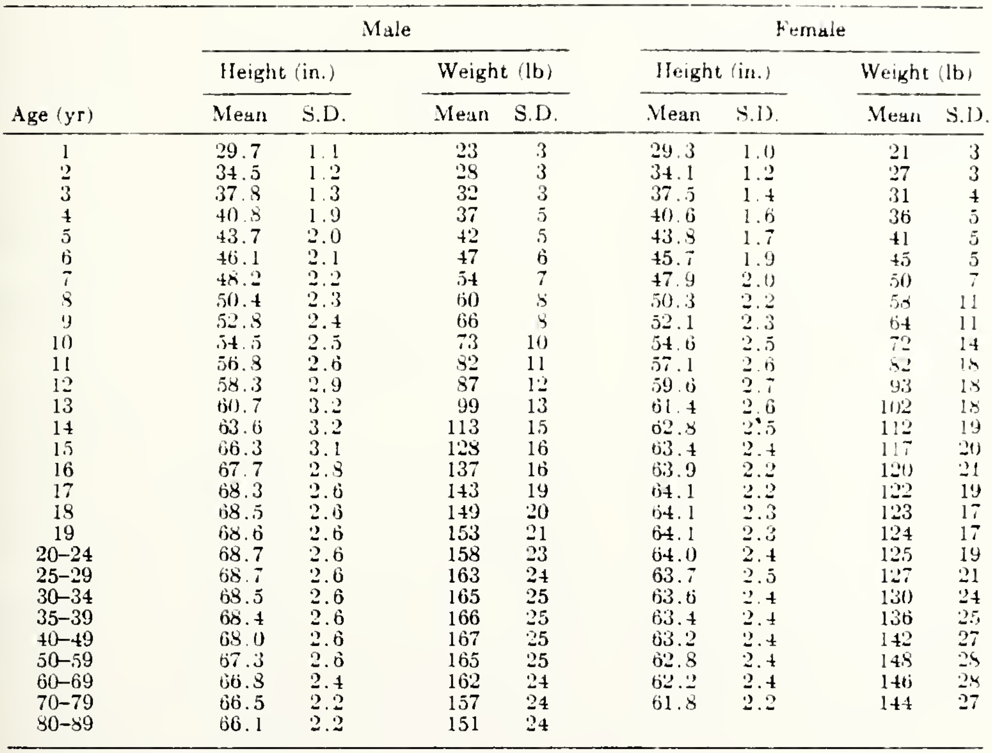
V. FACTORS AFFECTING STRENGTH

The discussion to this point has shown that basic physiological differences do exist between men and women which have the potential of affecting physical performance and work capacity. There are also important factors which result in a significant variability of work capacity not only between, but within the sexes, as well.

Age. At around ten years of age boys and girls are generally equal in strength,[31] and prior to puberty show no significant differences in maximal aerobic power.[32] After puberty significant differences begin to occur in stature, strength and aerobic power as depicted in Table I, with men being larger than women, on average, at any given percentile, for most body measurements.[33] Strength reaches its maximum in men in the mid to late twenties, remains there for five to ten years and gradually begins to decrease at an increasing rate.[34] At age forty an average man's strength will be approximately 95% of his earlier maximum, and at age fifty to sixty it will decrease to around 80%. Maximal strength is reached by women in their early twenties and remains there for about ten years also. The decline in strength for women is more rapid than in men, and at age fifty to sixty women will only be able to exert approximately 60% of their earlier maximal strength. Disagreement exists as to the exact reason for this decline in strength with increasing age. Simonson, in his book Physiology of Work Capacity and Fatigue, attributes the probable cause of this to

loss of active tissue in muscle and the central nervous system.[35] Astrand and Rodahl, however, see this strength decrement as a result of the decrease in the circulatory capacities of older people.[36] The decline in strength does not proceed at the same rate (this holds true for both men and women) for all parts of the body, with the hands and arms being affected less by age than the trunk and legs.

Stature. Body dimensions and stature correlate positively (for non-obese subjects) with work capacity for both men and women.[37,38] Within stature many other variables enter the picture to increase the variability of stature even more.



	Male				Female			
	Height (in.)		Weight (lb)		Height (in.)		Weight (lb)	
Age (yr)	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	29.7	1.1	23	3	29.3	1.0	21	3
2	34.5	1.2	28	3	34.1	1.2	27	3
3	37.8	1.3	32	3	37.5	1.4	31	4
4	40.8	1.9	37	5	40.6	1.6	36	5
5	43.7	2.0	42	5	43.8	1.7	41	5
6	46.1	2.1	47	6	45.7	1.9	45	5
7	48.2	2.2	54	7	47.9	2.0	50	7
8	50.4	2.3	60	8	50.3	2.2	58	11
9	52.8	2.4	66	8	52.1	2.3	64	11
10	54.5	2.5	73	10	54.6	2.5	72	14
11	56.8	2.6	82	11	57.1	2.6	82	18
12	58.3	2.9	87	12	59.6	2.7	93	18
13	60.7	3.2	99	13	61.4	2.6	102	18
14	63.6	3.2	113	15	62.8	2.5	112	19
15	66.3	3.1	128	16	63.4	2.4	117	20
16	67.7	2.8	137	16	63.9	2.2	120	21
17	68.3	2.6	143	19	64.1	2.2	122	19
18	68.5	2.6	149	20	64.1	2.3	123	17
19	68.6	2.6	153	21	64.1	2.3	124	17
20–24	68.7	2.6	158	23	64.0	2.4	125	19
25–29	68.7	2.6	163	24	63.7	2.5	127	21
30–34	68.5	2.6	165	25	63.6	2.4	130	24
35–39	68.4	2.6	166	25	63.4	2.4	136	25
40–49	68.0	2.6	167	25	63.2	2.4	142	27
50–59	67.3	2.6	165	25	62.8	2.4	148	28
60–69	66.8	2.4	162	24	62.2	2.4	146	28
70–79	66.5	2.2	157	24	61.8	2.2	144	27
80–89	66.1	2.2	151	24				

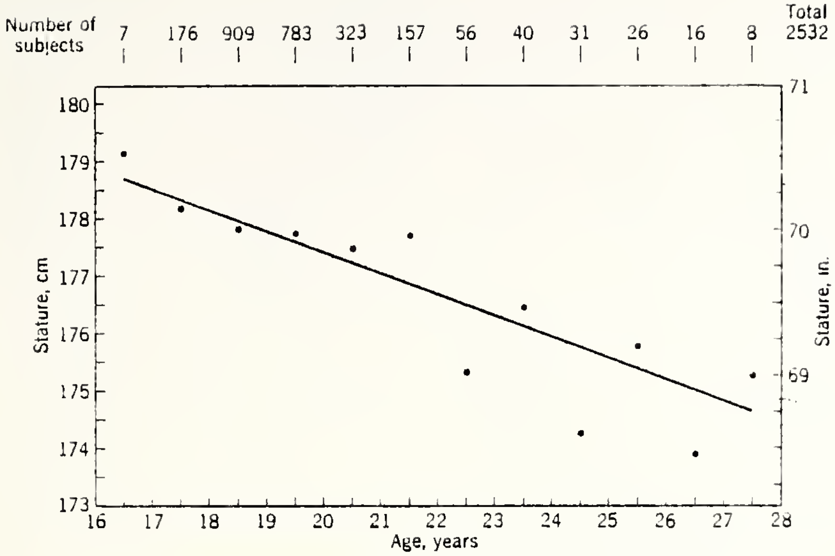
Stoudt et al. (1960).

Height and Weight of Men and Women at Different Ages. (From: Department of Defense, Human Engineering Guide to Equipment Design, McGraw-Hill, New York, 1972, p. 472)

Table I

Obviously age has an important effect on stature as already shown in Table I, with actual decreases in stature occurring as age increases. The difficulty encountered in determining the actual amount of stature decrement due to age lies in the problem of conducting longitudinal studies over the same subjects for the extended periods required. Compounding this even more is the phenomenom of increased stature in the population (secular change) from one generation to another. Cross sectional studies of military personnel for over the past hundred years have demonstrated this gradual increase in size from one generation to another, as have studies on the civilian population. A cross sectional study of 2532 college men aged sixteen to twenty-eight from New England, Middle and Far Western colleges in the United States demonstrated an average difference in stature across this age group of one and a half inches, and is shown below in Figure 8.[39] In a similar study of military personnel comparing stature of personnel involved in World War II and the Korean conflict, similar results were obtained and are shown in Figure 9. The overall trend from 1870-1980 is shown in Figure 10 and is taken from studies of United States military personnel in all branches of the service.[40] The decrease in stature in Figure 10 between the Civil War and World War I was explained as due to a period of history where the United States accepted large quantities of immigrants from other countries which tended to lower the overall mean stature.

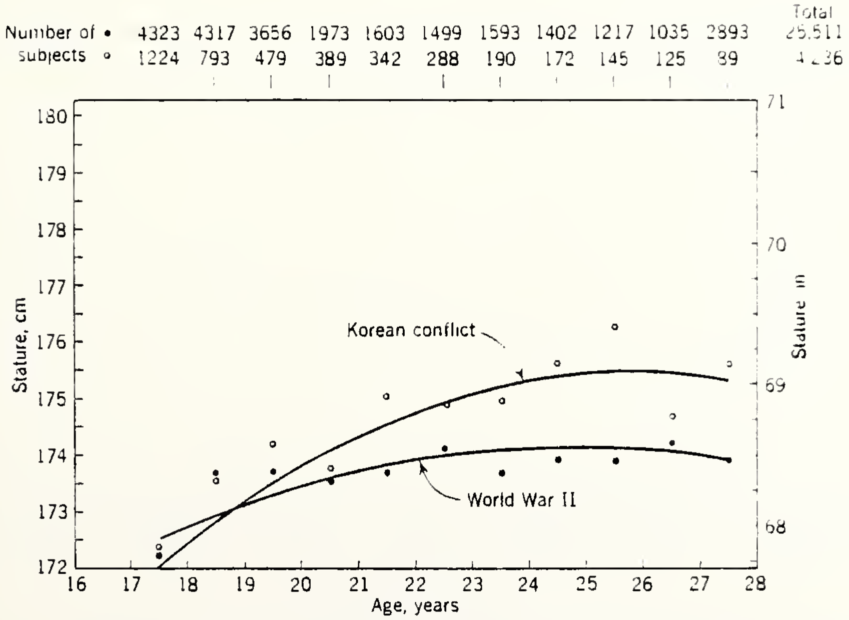
This brings in another factor of variability in stature, that of nationality. Because of differences in climate, diet,



Initial mean stature by age group in the college study

(From: Bennett, E., Degan, J. and Spiegel, J., Human Factors in Technology, McGraw-Hill, New York, 1963, p.152)

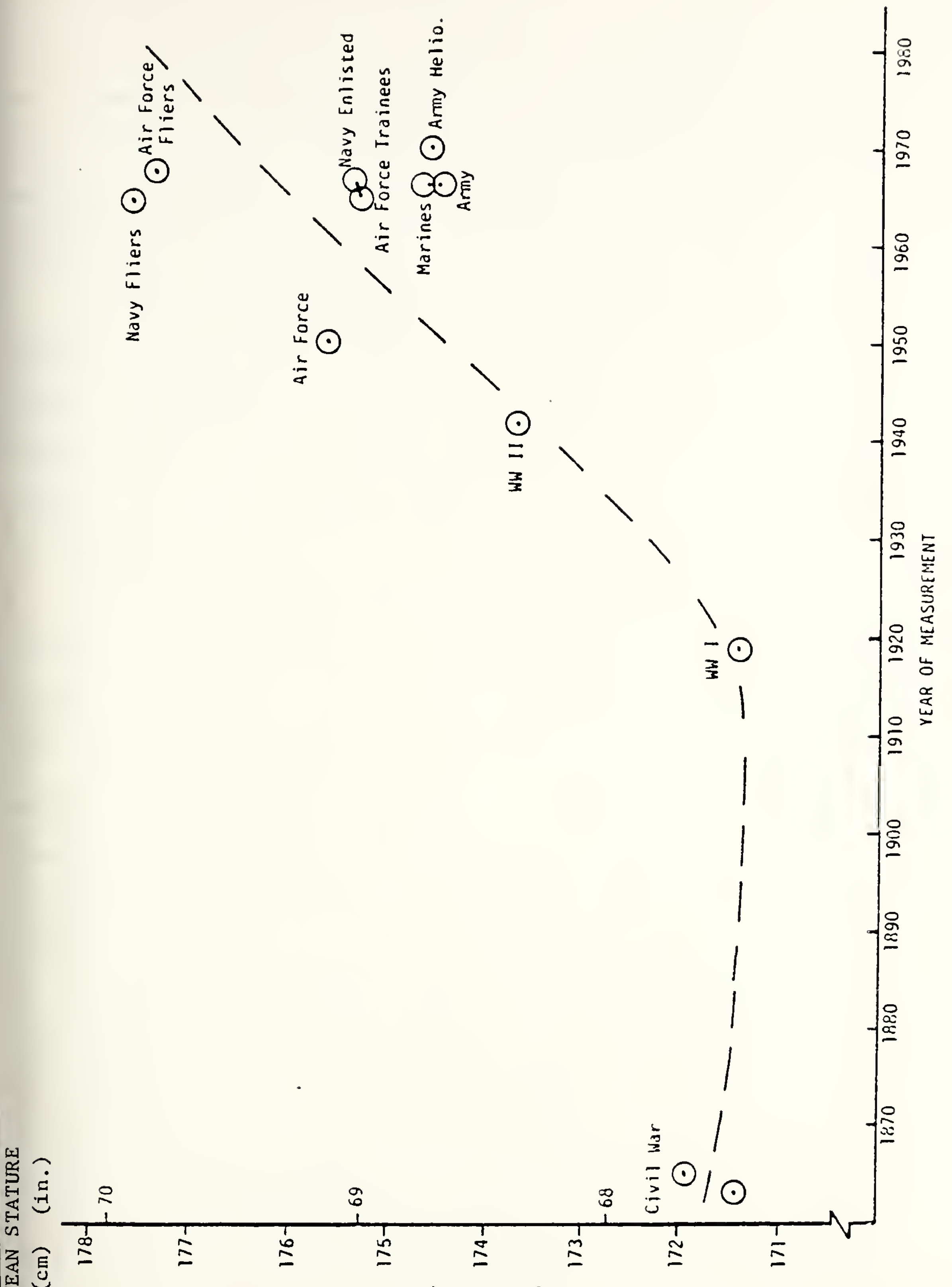
Figure 8



Mean stature by age group in World War II and Korean-conflict samples

(From: Benneth et al., p. 150.)

Figure 9



Secular trend in stature for young U.S. males: 1870-1980.

Figure 10

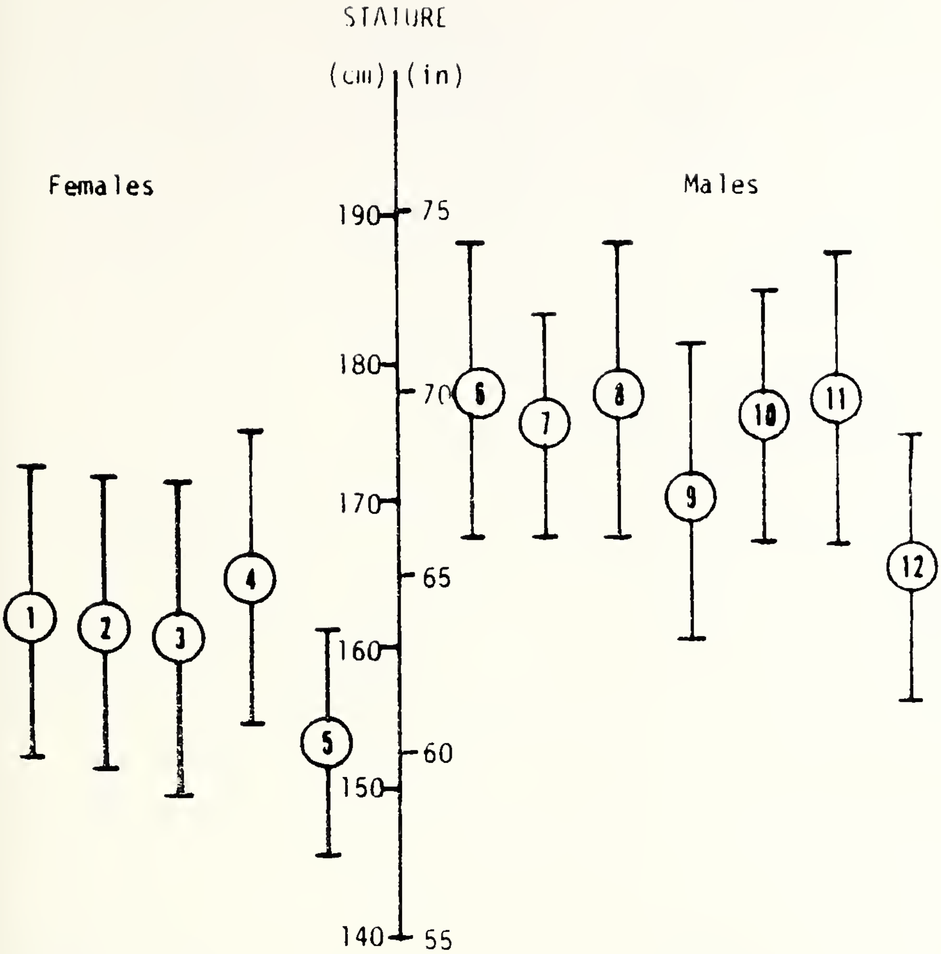
(From: National Aeronautics and Space Administration, Anthropometric Source Book, Volume I: Anthropometry for Designers, Webb Associates, Yellow Springs, Ohio, 1978, p. II-56)

and culture, e.g. sex roles, stature varies from one nationality to another.[41] Examples of this variability in both height and weight are shown in Figure 11 for stature, and Figure 12 for weight.

Within each nationality, ethnic differences also exist adding even more variability to differences in stature.[42] This is especially important for the population of the United States because of its large ethnic variation. The range of variation between black, white, and oriental male subjects is shown in Figure 13, and for women in Figure 14.

The importance of stressing the differences in stature lies in the positive correlation of stature to work capacity mentioned earlier. Because of the extreme variabilities of stature between nationalities, ethnic groups, age groups and generations, variabilities in work capacity will occur as well. Because of the secular changes in generations, physical performance as well can be expected to increase from one generation to another.[43]

Cultural Influences. The forces society exerts on the people within it, while beyond the scope of this paper, have an enormous impact on physical performance. By defining sex roles and setting standards for masculine and feminine behavior, many opportunities for women and young girls to develop their physical capabilities and work capacity go unrealized. Where many young boys are encouraged to develop their physical capabilities through participation in sports and strenuous activities, many young girls are either prohibited or discouraged

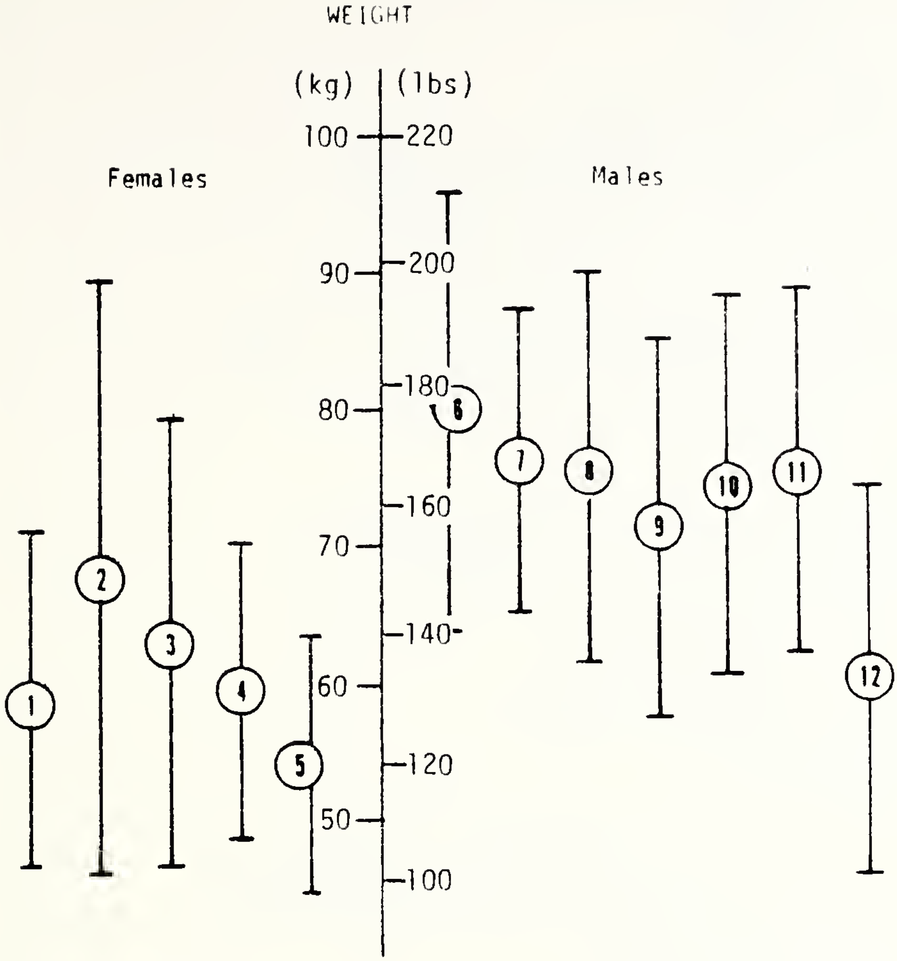


1. USAF
2. U. S. HEW civilians
3. British civilians
4. Swedish civilians
5. Japanese civilians
6. USAF fliers
7. NASA astronauts
8. British fliers
9. Italian military
10. French fliers
11. German Air Force
12. Japanese civilians

Range of variability (5th-95th percentile) in stature for selected populations.

(From: National Aeronautics and Space Administration, p. II-40.)

Figure 11



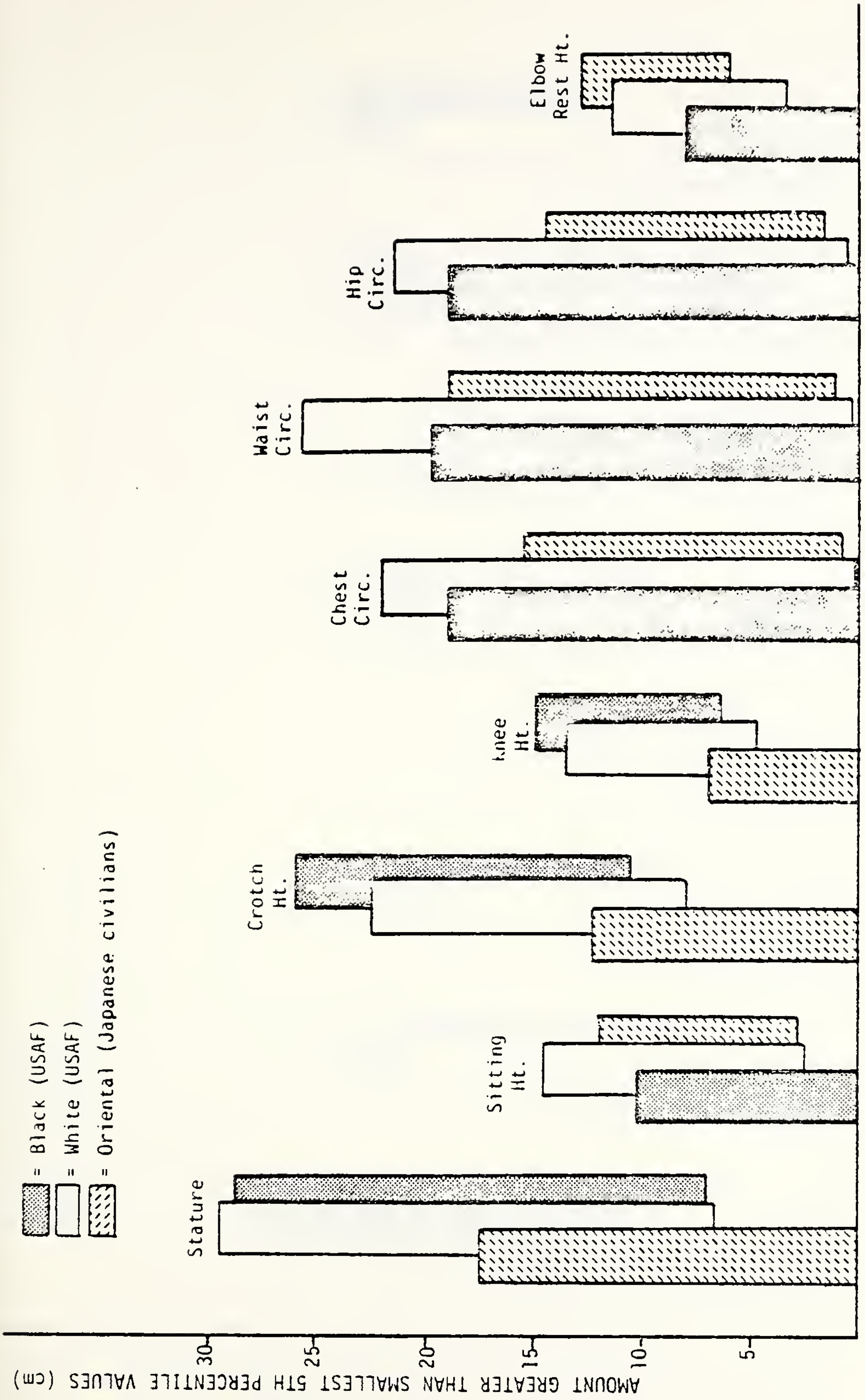
1. USAF
2. U. S. HEW civilians
3. British civilians
4. Swedish civilians
5. Japanese civilians

6. USAF fliers
7. NASA astronauts
8. British fliers
9. Italian military
10. French fliers
11. German Air Force
12. Japanese civilians

Range of variability (5th-95th percentile) in weight for selected populations.

(From: National Aeronautics and Space Administration, p. II-41.)

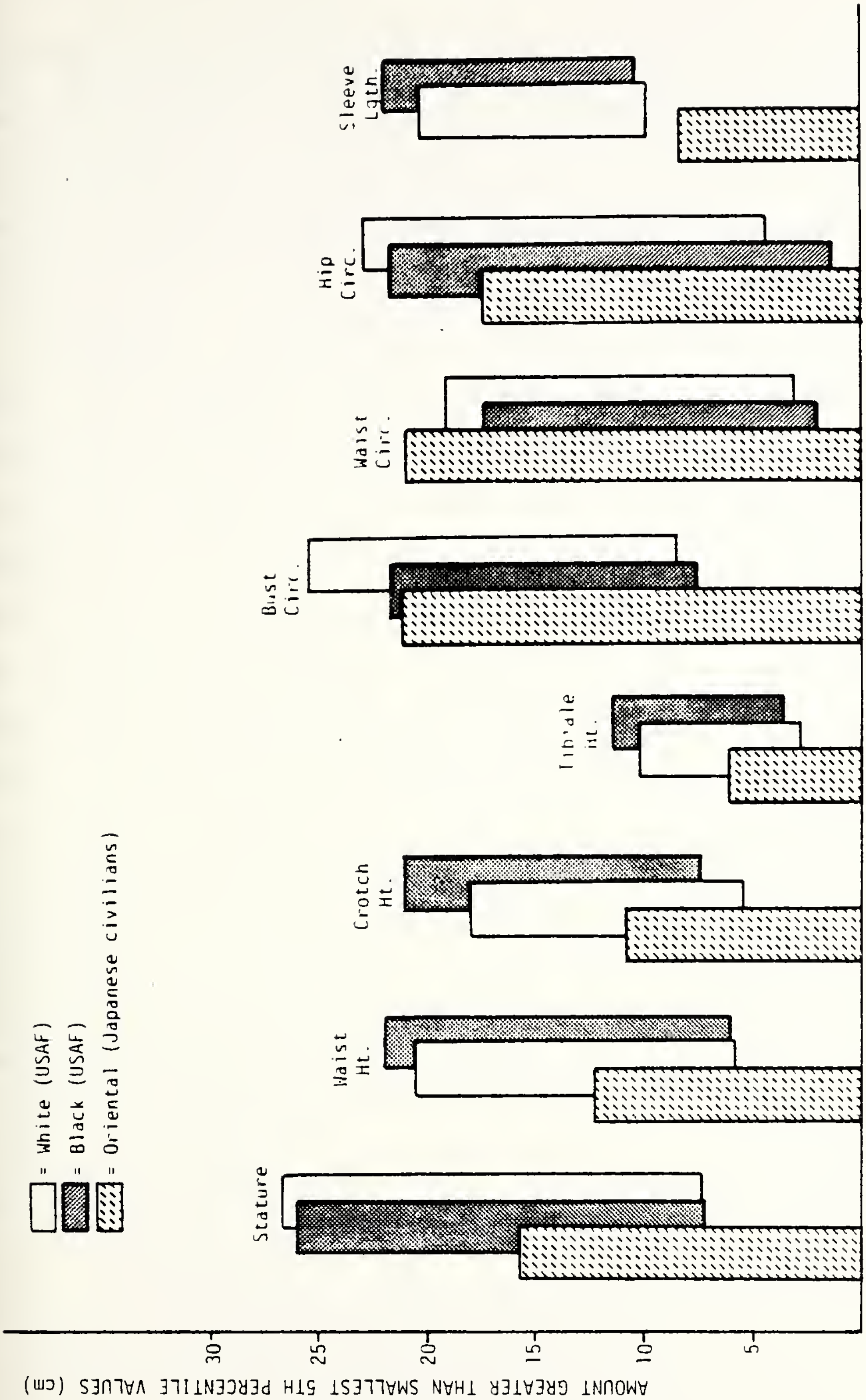
Figure 12



Range of variation between males of three racial groups for selected body dimensions (smallest 5th to largest 95th percentile).

(From: NASA, p. II-36)

Figure 13



Range of variation between females of three racial groups for selected body dimensions (smallest 5th to largest 95th percentile).

(From: NASA, p. II-37)

Figure 14

from doing so on the basis of maintaining "appropriate" feminine behavior. Although this situation has changed dramatically in the past twenty years, much additional change is required before men and women will have equal opportunities in this area.

Training. Training has an important effect on an individual's work capacity, both in terms of skill enhancement and increasing physical fitness. Training in physical fitness brings about many beneficial changes in untrained people. The expansion of the chest is increased, the breathing rate is slowed and more lung surface area may be made available for the inhalation of oxygen.[44] The heart becomes stronger and works more efficiently, blood capilarization to the muscles occurs, and the muscles themselves can increase their contractile force. In their study "Long Term Physical Training Effect in Sedentary Females"[45] John S. Hanson and William H. Nedde concluded, "... the trainability of non-athletic females and their oxygen transport systems does not differ from that of their male counterparts and identical benefits can and should be gained by regular activity in both sexes." This is not to say that all women can be trained to become as strong as all men, but the percent of improvement should be roughly equivalent in untrained men and women with the same initial level of fitness subjected to the same training loads.

The exact training load imposed on people to bring about optimal results varies from one person to another depending both on their age and beginning level of fitness.[46] As

training progresses the training load must be increased, as the more physically fit a person becomes the more it will take to improve upon that fitness.

In 1978 the United States Army conducted a study of a physical conditioning program of conditioning thirteen female soldiers, in order to determine if they could successfully load and fire 105 mm and 155 mm howitzers.[47] The subjects were mainly from administrative and clerical fields and participated in a three-week physical conditioning program closely geared to the requirements of firing these weapons. The training began with an assessment of each soldier's beginning state of fitness, and initial loads were imposed accordingly. The primary cardiovascular exercise was jogging. Strength training on a universal weight machine consisted of squats, forearm lift, dead lift and curl. Endurance training included bench press, leg press, situps on the inclined board and back extensions. Performance was monitored and loads increased on an individual basis every two days. At the end of the three-week period the test directors conducted an experiment to determine if women who are physically fit would be able to maintain the strength and endurance necessary for the firing sequence of the 105 mm and 155 mm howitzers. The doctrinal rate of fire is four rounds per minute for the first three minutes and then one round per minute thereafter for a period not to exceed 5 minutes for the 155 mm howitzer, and ten rounds per minute for the first three minutes, then three rounds per

minute thereafter for a period not to exceed 5 minutes for the 105 mm howitzer. The crew size for the 105 mm howitzer is four and six for the 155 mm howitzer.

The ammunition for the 105 mm howitzer weighed forty-five pounds and for the 155 mm howitzer ninety-five pounds. Each round had to be carried approximately eight to ten feet. The women not only met the rate of fire on both howitzers, but in several instances actually exceeded it. By the conclusion of the conditioning program the women had experienced an average increase of 13% in the forearm lift (from 82 to 93 pounds), a 20% increase in squats (from 150 to 180 pounds), 14% increase in curls (from 22 to 25 pounds) and a 38% increase in the dead lift (from 58 to 80 pounds). The point made by this study is that a well structured conditioning program, closely tailored to individual capabilities with periodic increases in the training load based on individual performance, can achieve significant results even in a relatively short (3 weeks) period of time.

Menstrual Cycle. Another important influence on work capacity is the menstrual cycle. Although two noted psychologists[48] claim to have discovered a cycle in men having psychological effects, they have not as yet published any substantive evidence supporting their claims.

Almost all women of childbearing age are subject to the regular physiological changes involved in the reproductive cycle. This cycle begins with ovulation and, if pregnancy does not

occur, ends with menstruation. The cycle is often broken down, for convenience, into four phases: pre-ovulatory, ovulatory, pre-menstrual and menstrual.[49]

Measurements of blood pressure, metabolic rate, pulse rate, temperature, and weight have all been found to vary with the menstrual cycle, and although there is much disagreement over the direction and degree of variance, it is agreed that, in general, these bodily measurements increase during the pre-menstrual phase and decrease below the normal level when menstruation begins.[50]

The effect which the menstrual cycle exerts on the ability to carry out tasks depends upon the severity of the task and the extent to which extra effort can be exerted to offset any detrimental effects.[51] That is to say, a person not working at full capacity will be able to put forth a little more effort to compensate for any adverse effects of the menstrual cycle, but when working at or near full capacity, this extra effort may not be available or insufficient to compensate.[52]

Individual difference between women also play a part in the effects of the menstrual cycle both as to degree of the effect and when in the cycle the effect occurs.[53] Peter V. Karpovich, in his book, Physiology of Muscular Activity,[54] mentions a study of 111 athletic women participating in track and field events. This study found no decrease in performance for 55% of the women and a decrease for the remaining 45% at some time during their menstrual cycle. Other studies indicate that approximately 1 woman out of 4 is adversely affected to

a high degree by the menstrual cycle, and 2 out of 3 women experience some disturbances of a lesser degree during their menstrual cycles.[55]

Biomechanical Considerations. In the earlier discussion concerning the use of the human skeleton as a system of levers powered by muscles, it was mentioned that the amount of muscular force required to overcome the resistant force and cause desired movement was dependent on the length of the force arm as compared to the length of the resistance arm. Referring back to Figure 3, the force arm was shown as the distance from the elbow (fulcrum of the lever) to the point where the force was applied (where the tendons from the muscle attached to the bone). The resistance arm was shown to be the distance from the point of application of the resistant force to the elbow. Stated mathematically, a muscular force (MF) required to overcome a resistant force (RF) with a given force arm (FA) and a given resistance arm (RA) would be expressed as $MF = \frac{RF \times RA}{FA}$, and the mechanical advantage would be expressed as $MA = \frac{FA}{RA}$.

If the force arm was made longer, with the same resistant force and resistance arm, then the muscular force required to overcome the resistant force would be less. By the same token, if the resistance arm was made longer, with no change in the resistant force and force arm, the muscular force required to overcome the resistant force would be greater.

With the mechanical advantage defined as the distance from the elbow (using the arm as an example) to the point of muscle attachment divided by the distance from the elbow to

the hand (point of application of the resistant force), a person with a shorter forearm (with the distance from the elbow to the point of muscle attachment remaining the same) would have a greater mechanical advantage than a person with a longer forearm. This becomes important when it is realized that $MF = \frac{RF}{MA}$, meaning that less muscular force is required to overcome a given resistant force for the person with the greater mechanical advantage.

However, there is virtually no information available in the current literature as to how the mechanical advantage varies among people of different stature and between the sexes. Because of its potential for assessing strength capabilities and the importance of understanding how physical sex differences in strength might be affected, this is clearly an area requiring further study.

VI. COMPARATIVE STRENGTH DIFFERENCES

In discussing the degree to which men and women differ in strength and endurance, it must be remembered that there are essentially two types of strength: dynamic and static. Dynamic strength is usually measured as some form of endurance such as running, long distance skiing, and swimming. In this type of activity a large surge of strength is not always required, but a well developed cardiovascular system is necessary to deliver sufficient amounts of glucose and oxygen to the muscle cells and to remove contaminants.

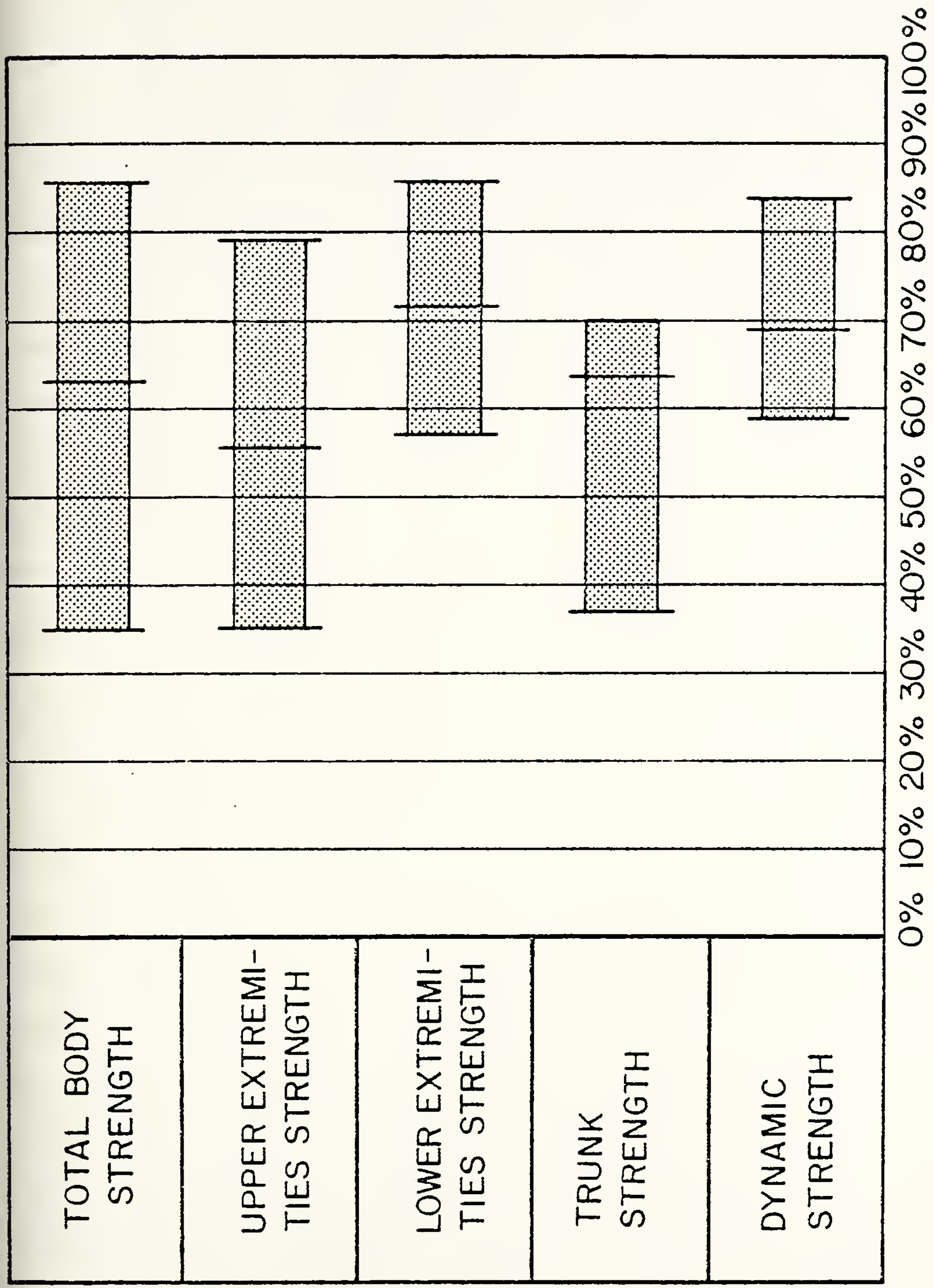
Static strength is the ability to exert the forces required to overcome a resistant force. It is this static strength which is repeated over time which comprises dynamic strength.

Strength is situational and can vary within an individual according to body position,[56] whether gravity is working for or against that person, and whether the person is able to use his own body weight to help accomplish his task. An example of this would be of two individuals who were able to exert the same amount of force on a similar object (both have equal muscular strength), but one weighs 40 pounds more than the other. The lighter person would have an advantage in performing pull ups or push ups where not as much weight was to be moved. The heavier person would have an advantage in wrestling, a tug of war or any task such as pushing where his extra weight could be brought to bear on the task. Some of the more traditional

methods of strength measurement and testing for groups of people such as push ups, pull ups and sit ups may serve more as an indicator of a person's ability to move his/her own weight than as a basis for comparing muscular strength between two different individuals.

In reviewing the literature on physical strength differences between men and women, one particular article stands out. In 1976 Lloyd L. Laubach conducted a review of the literature on the comparative muscular strength of men and women, and wrote an article which appeared in the May issue of, Aviation, Space, and Environmental Medicine,[57] and was subsequently expanded and included as a complete chapter (concerning the same subject) in the National Aeronautical and Space Administration's (NASA), Anthropometric Source Book, Volume I: Anthropometry for Designers.[58]

With his stated objective as "to review the selected studies of comparable static and dynamic muscle strength capabilities for men and women and to document these differences," Laubach presents detailed statistical information on comparative muscular strength parameters of men and women from approximately 70 static and dynamic strength measurements. The results are presented in both tabular and graphic form. Selections from Laubach's study are included here in Appendix A and illustrate in graphical form the mean ± one standard deviation of men's and women's muscular strength and the average percentage of women's muscular strength as compared to men's average muscular strength. The authors and year of each study are presented to the side of the data.



The range and average mean percentage of women's strength as compared to men's average strength. (100% = men's average strength)

(From: NASA, p. VII-50)

Figure 15

As a summary of the data presented in Appendix A, Figure 15 also includes a calculation for total body strength. This was determined by summing the mean percentage of women's strength compared to men's strength for each strength capacity and dividing by the number of measurements observed. The horizontal bars indicate the ranges of the mean percentages of women's strength as compared to men's strength and the vertical slashes show the average mean percentage of the difference in women's strength as compared to men's strength. For example, in total body strength, women's mean total body strength varies from 35% of men's mean total body strength to 85% of men's mean total body strength, with the average mean percentage of women's total body strength equal to approximately 63% of the mean total body strength of men. The other bars of Figure 15 can be interpreted in a similar manner.

The fact that the average mean total body strength of women is equal to 63% of the mean total body strength of men can be misleading because of the broad range of mean percentage differences which exist across the spectrum of the muscular strength comparisons. The measurements of upper extremity strength in Figure 15 show a range from 35% to 79% of men's upper extremity strength with an average of 55.8%. In the lower extremities the range was 57% to 86% with a mean of 71.9% of men's lower extremity strength. For trunk strength the ranges are 37% to 70% with a mean of 63.8% and for the dynamic strength measurements the range varied from 59% to 84% of the men's with an average mean of 68.6%. The emphasis on Figure 15

should be placed on the ranges of the differences (35% - 86%) and not on the average values if any meaningful interpretation is to be made.

In his search of the literature, Laubach also found that in at least half of the data on strength which was reported the fifth percentile value of strength measurements for men exceeded the ninety-fifth percentile value for women. This serves as an added reminder of the importance of the variability in the ranges of the measurements instead of using the average values.

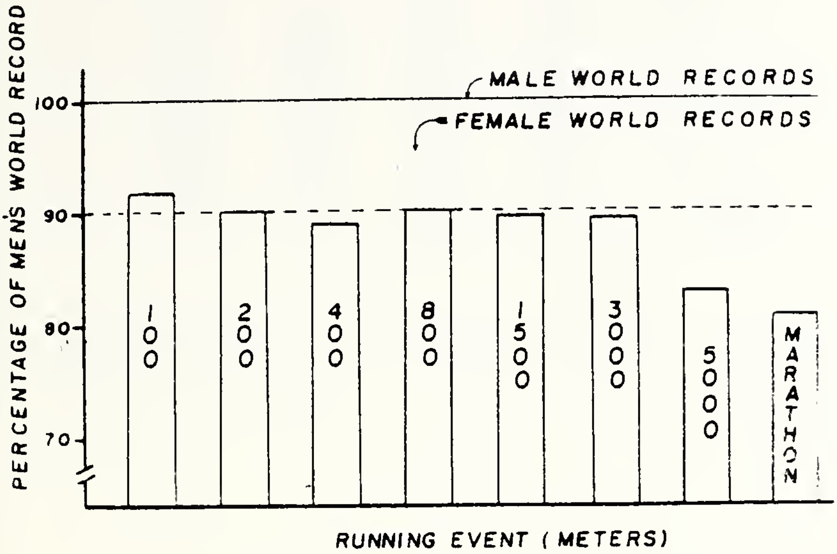
The dynamic strength data in Laubach's study pertained to basic manual handling task such as lifting, lowering, pushing and pulling and were not necessarily oriented toward the more extreme aspect of endurance in dynamic strength.

A source of the more extreme aspect of endurance in dynamic strength can be found in sports literature, especially that concerning marathon (26.2 miles) running.

In their article "Biomechanical Comparison of Male and Female Distance Runners," by R.C. Nelson, Cristine M. Brooks, and Nancy L. Pike,[53] (all from the Biomechanics Laboratory at Pennysylvania State University) a comparison of male and female world records (as of 1976) yields the interesting information shown in Figure 16.

In Figure 16, where again the women's records are expressed as a percentage of the men's records, the mean time is almost 90% of the men's mean time. The authors attribute the lesser

percentages in the 5000 meter race and the marathon to the fact that both of these events are relatively new to women's competition and express their expectations that this gap will soon be reduced.

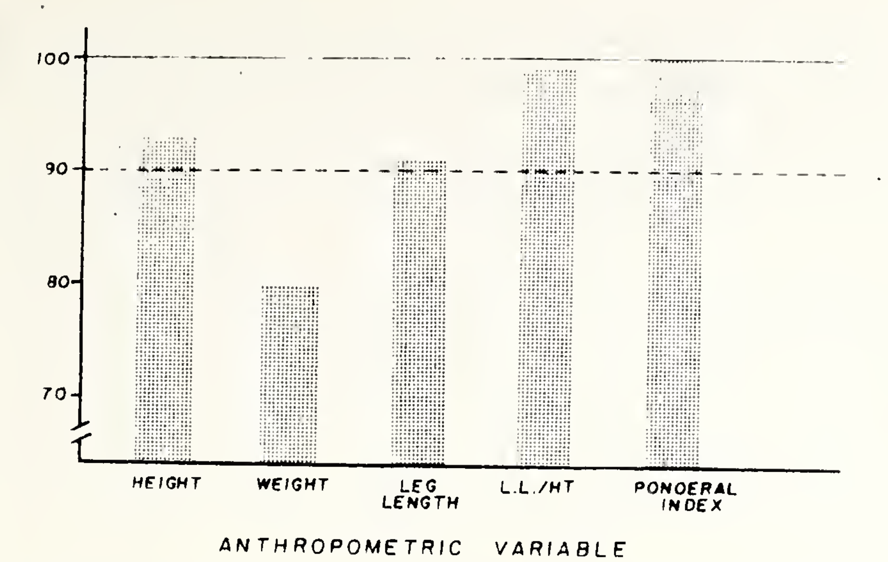


Comparison of male and female world records: 1976.

(From: Nelson, R.C. et al, "Biomechanic Comparison of Male and Female Distance Runners," in Paul Milvy (ed.), The Marathon: Physiological, Medical, Epidemiological, and Psychological Studies," New York Academy of Science, New York, 1977, p. 794.)

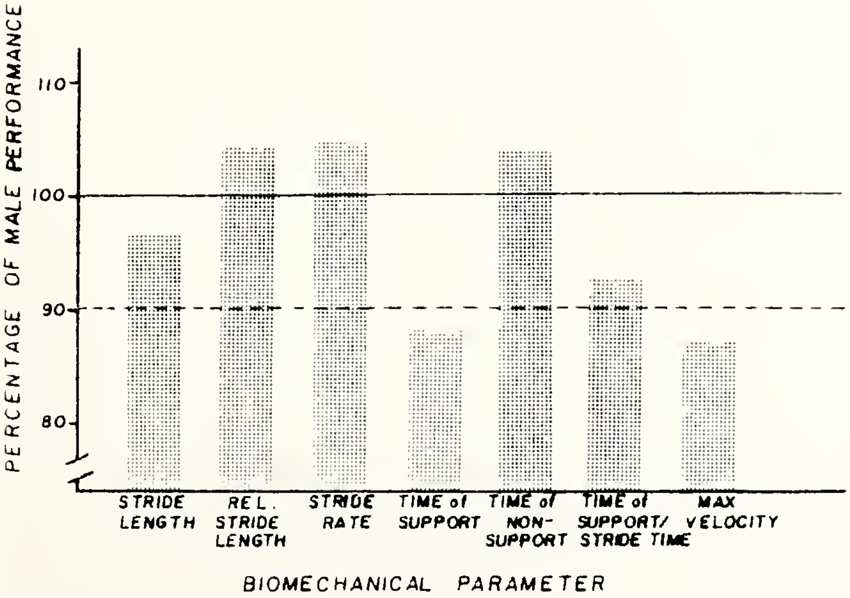
Figure 16

In another comparison, the authors studied 21 of the best American female runners, 14 comparable male runners, and 10 male runners from Pennsylvania State Unversity. The anthropometric variables of height, weight, leg length, leg length/ height and ponderal index (a measure of body build equal to height divided by the cube root of weight) were determined. Their results are shown in Figure 17. Figure 18 compares the same men's and women's biomechanical parameters of stride



Anthropometric variables in the comparison of men and women runners. (From: Nelson et al., p.797)

Figure 17



Biomechanical parameters in the comparison of men and women runners. (From: Nelson et al.,p.806)

Figure 18

length, relative stride length, stride rate, time of support, time of non-support, time of support/stride time, and maximum velocity. Women's scores are again presented as a percentage of the men's scores.

The procedures used in gathering this information were to have the subjects run at maximum velocity, and at three predetermined paced velocities (covering a range of speeds from marathon pace to sprint speed) over a specified distance on a regular track.

In the biomechanical comparisons shown in Figure 18, it can be seen that the women made up for their shorter leg length by faster stride rates and longer relative stride lengths. The authors make note of the women's higher time of non-support (flight) and the shorter stride rate for the women as an indication of a running pattern significantly different than the men's pattern. The women's mean maximum velocity was equal to approximately 88% of the men's mean maximum velocity. These findings cannot be generalized to hold for the general population of men and women, but do represent the physical capacities of highly trained men and women runners.

Searching through old sports records sheds light on an interesting phenomenon, the fact that women are now equalling and even surpassing past men's records. Looking at the past sports records in track and field for American men and women in Frank G. Menke's The Encyclopedia of Sports,[60] one sees that in 1891 the men's record for the 100 yard dash was 10.2 seconds. This was equalled by the women's record for the same

event in 1970. The current men's record for the 100 yard dash (as of 1976, which is the most recent score which appears in Menke's book) is 9.2 seconds. Looking at records for the 8 pound shot put, the men's 1934 record of 55 feet and 5 inches was nearly equalled by the women in 1976 who put the shot 54 feet and 4 inches. The men's 1976 record for this event was 69 feet 4.75 inches. The event with the least years between men's accomplishing a record and women equalling it is the discus throw. Here the 1947 record for men was 174 feet 1.5 inches, which a woman nearly tied in 1976 with a throw of 174 feet and 1 inch.

Some of the reasons given by various authors for the fact that women are now equalling and surpassing past men's performance are secular change[61] (the increase in stature from one generation to another) and the increased opportunities for women to participate under better coaching and improved training methods.[62]

VII. CONCLUSION

In conclusion, the basic physiological differences which occur between men and women (such as cardiovascular system, hemoglobin content of the blood, pulse rate, heart size, stroke volume, sweat rate, vital capacity, aerobic power, stature, and weight) undoubtedly play a major part in the differences between the sexes in work capacity, physical performance and endurance. Other factors such as opportunities to participate in strenuous activities, social customs (and barriers), effects of aging and the menstrual cycle also influence these differences.

Increased opportunities to participate in sports and other strenuous activities, and the revised cultural customs of an 'enlightened' society tend to lessen the sex differences which now exist.

Many differences which do exist have an organizationally significant effect only at the upper limit of women's work capacity. Studies such as the one the Army conducted concerning the operation of the 105 mm and 155 mm howitzers show that the upper limit of women's strength is often either unknown or poorly understood, and that such limits frequently need not even be approached, let alone exceeded, given a proper understanding of job requirements and a sound physical conditioning program.

This is not meant to imply, however, that all jobs should be open to women with no considerations given to strength requirements. Some jobs exceed the strength capabilities of

of many men. The job of Infantryman in the Army and Marine Corps is perhaps one of the most physically demanding in the world. In combat, the Infantryman must not only be able to carry heavy loads for extended periods of time in all extremes of weather over inhospitable terrain, but he must be capable of engaging in combat (hand-to-hand if necessary) with an enemy who is often more rested than he. Not only does his own life depend on his training, strength, stamina, and discipline, but the lives of his comrades as well.

Given the great variability of women's strength presented by Laubach, combined with the fact he found (in at least 50% of the data he studied) that the 5th percentile value of men's strength scores exceeded the 95th percentile of women's strength scores, the general use of women in the most physically demanding jobs would be clearly inappropriate.

Strength is specific, not only to the person performing a task, but to the task as well. For this reason, jobs must be thoroughly task analyzed so that specific strength requirements can be determined and people assigned accordingly.

The study of the 13 Army women firing the artillery pieces proves to be a good case in point. Without any task analysis of the duties required in the artillery field, one might erroneously conclude that, since the study demonstrated the women's ability to successfully load and fire the weapons, women should be allowed to enter this career field in the military. However, a detailed task analysis of artillerymens' duties might uncover other requirements not directly related to actually firing the

weapon. For example, task analysis might find that artillerymen have to unload, carry and store heavy boxes of ammunition and supplies, provide perimeter security for defense of the weapons, dig trenches, build bunkers, and fill sand bags used in the fortification of their gun emplacements. The rates of fire might greatly exceed the 8 minute period over which the women were tested. In addition, the requirements for accuracy of fire might very well exceed that obtained by the women during the test (of which the study made no mention). In short, the importance of task analysis cannot be over emphasized. In this regard, much additional work needs to be done by the military and civilian sector, not so much to preclude participation by women, but to ensure inclusion when qualifications meet job requirements.

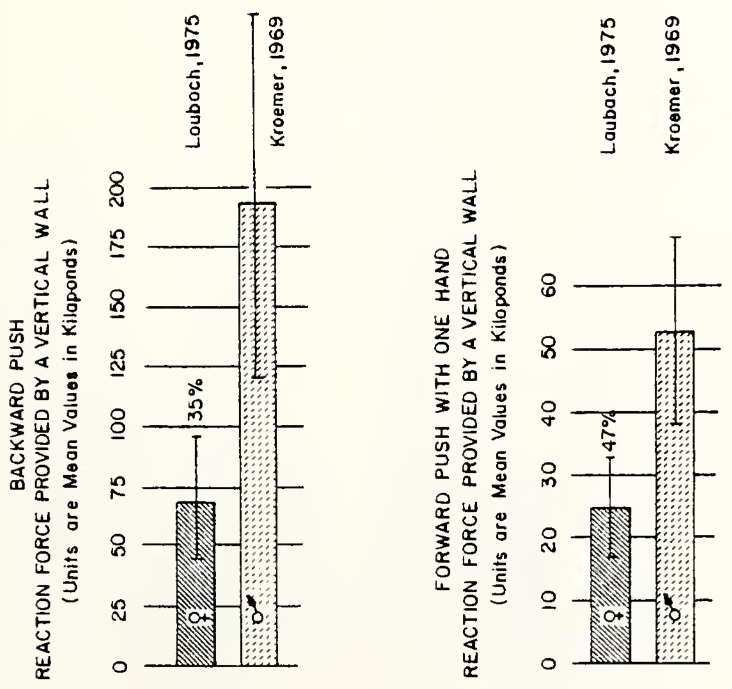
Strength differences between the sexes are significant both as to degree and scope. With women's mean total body strength varying over the broad range of from 35% to 85% of men's mean body strength, careful consideration must be given as to which jobs both men and women should be allowed (or expected) to perform in order to preclude the loss of valuable equipment and even more valuable lives. Hurried and incomplete solutions to this problem, rushed by pressures to seem fair and impartial, will only result in the creation of more problems.

Additional work and research also needs to be done in the area of strength testing. Although the results of clinical studies and athletic events do provide some insights to work

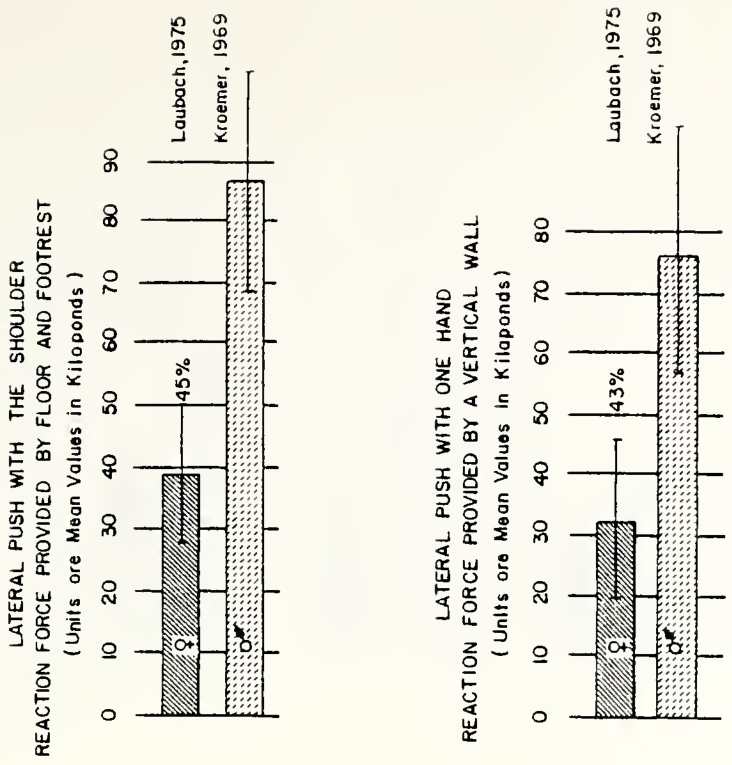
capacity, they can in no way substitute for knowing the requirements of the work environment. To be meaningful, any strength testing and measurement must adhere as closely as possible to job requirements. Only then can job requirements mesh with physical and mental qualifications to produce an effective worker, soldier, sailor, or Marine.

APPENDIX A

COMPARATIVE MUSCULAR STRENGTH DATA FOR MEN AND WOMEN

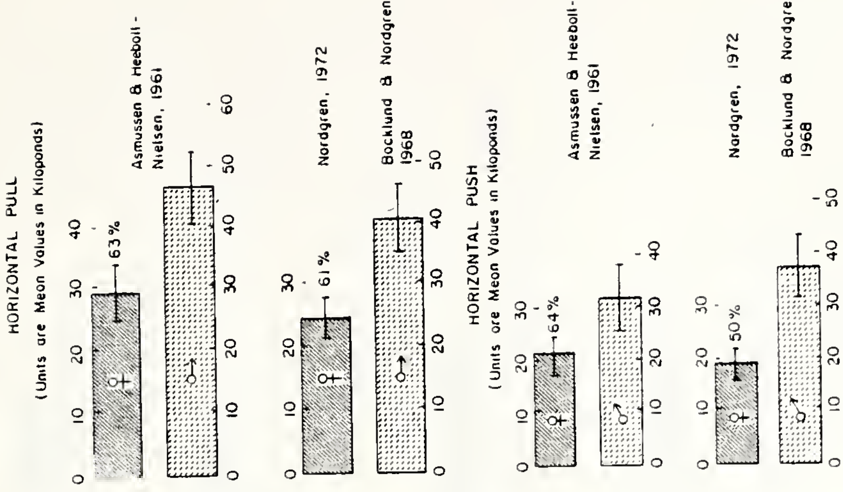


Female/male strength comparison: upper extremities.

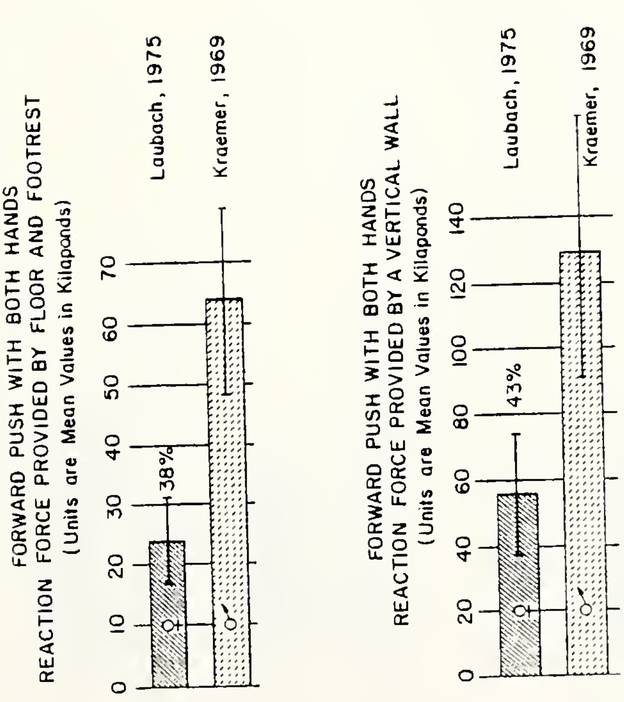


Female/male strength comparison: upper extremities.

National Aeronautics and Space Administration (NASA), Anthropometric Source Book, Volume I: Anthropometry for Engineers, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-36.



Female/male strength comparison: upper extremities.



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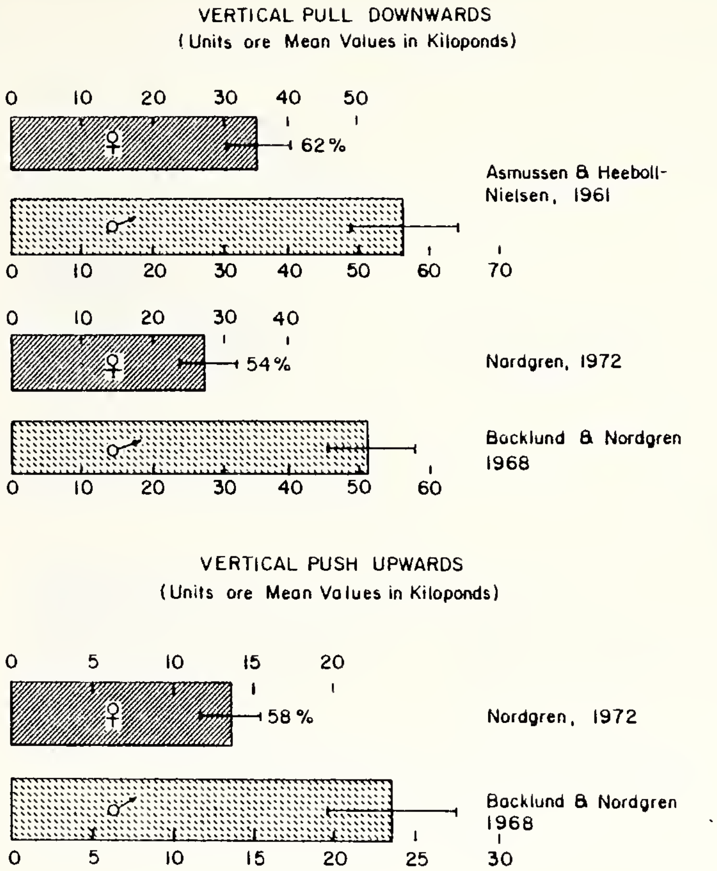
National Aeronautics and Space Administration (NASA), *Anthropometric Source Book, Volume I: Anthropometry for Engineers*, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-37.



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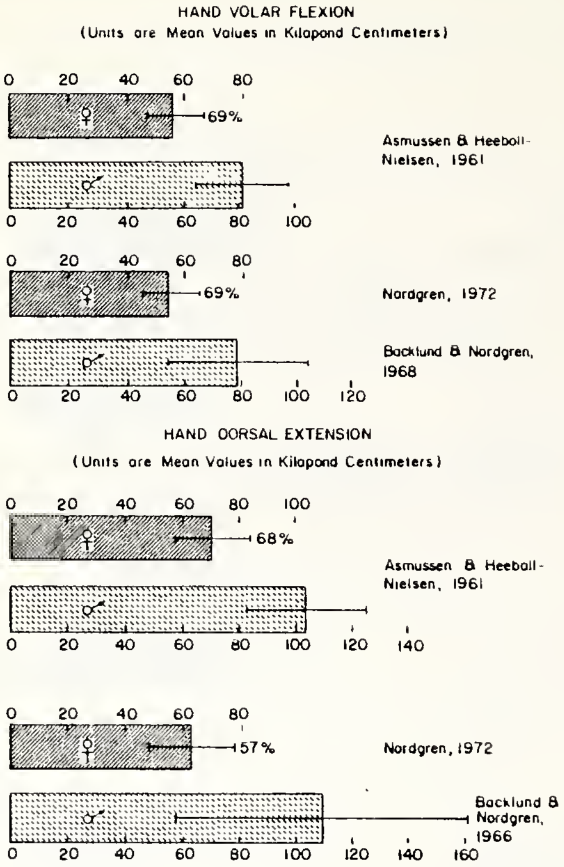

Female/male strength comparison: upper extremities.

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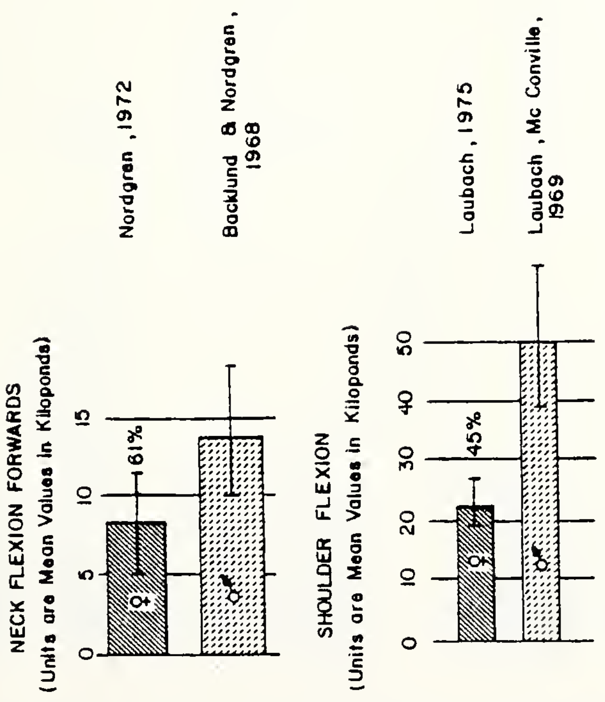

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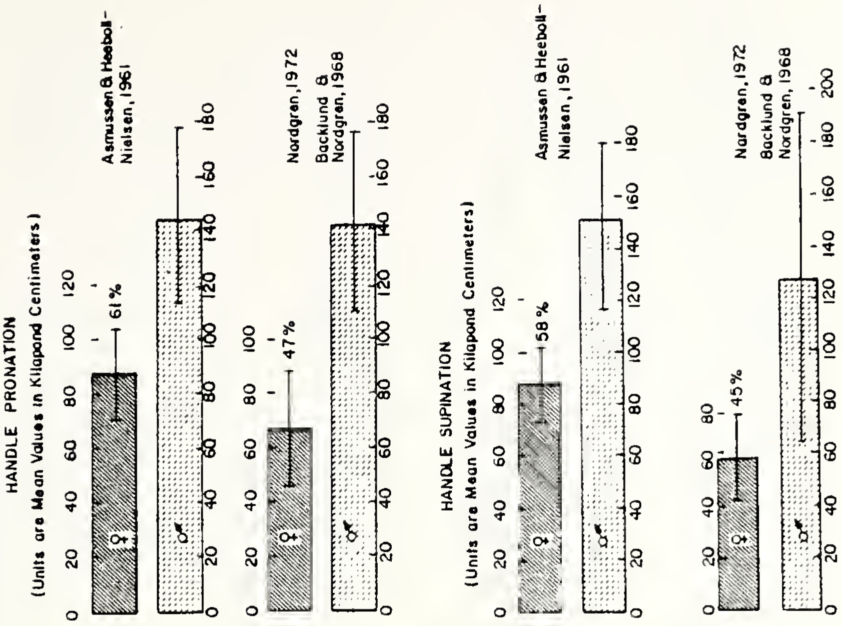
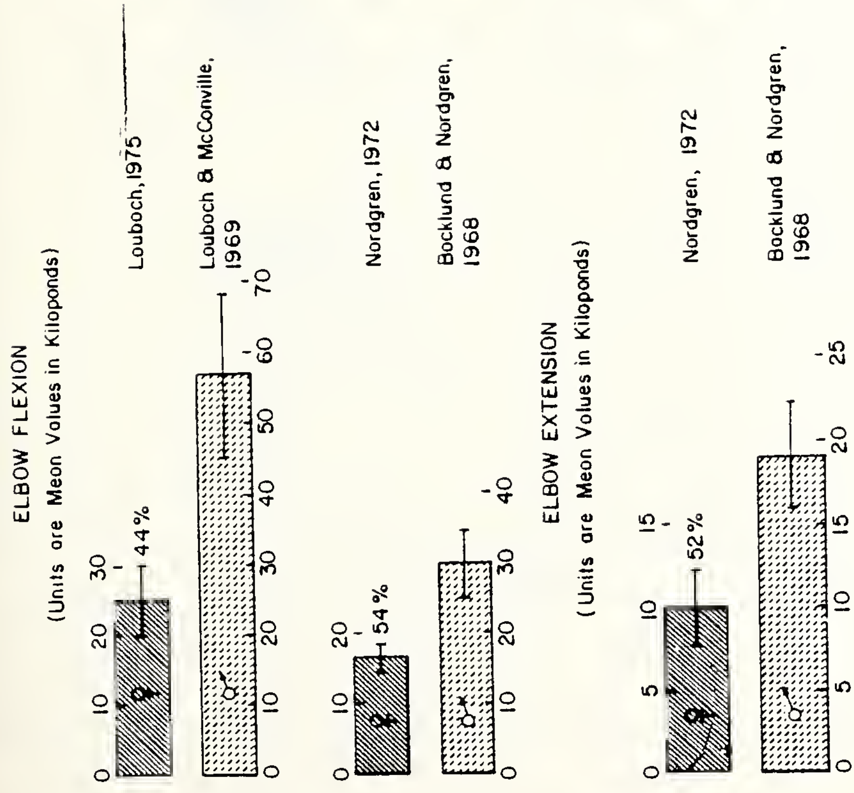
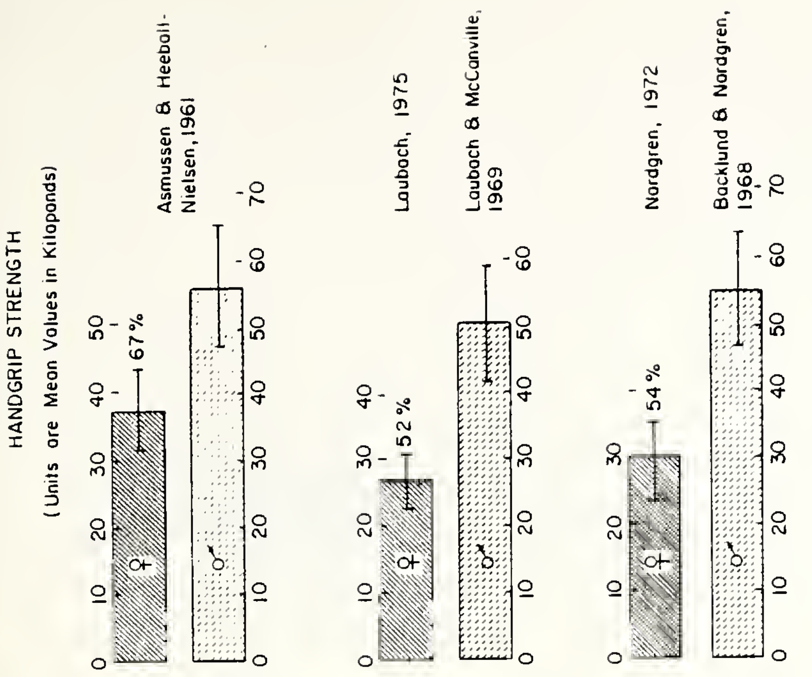


Female/male strength comparison: upper extremities.

National Aeronautics and Space Administration (NASA), Anthropometric Source Book, Volume I: Anthropometry for Engineers, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-39.

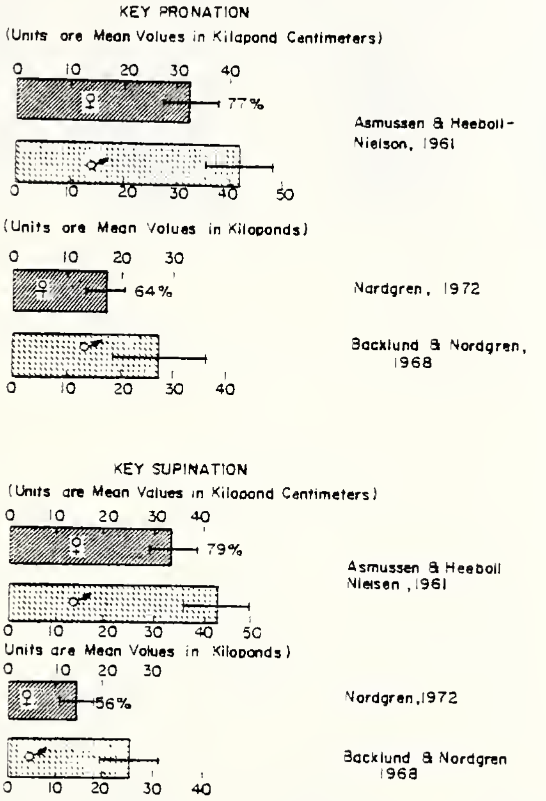


Female/male strength comparison: upper extremities.



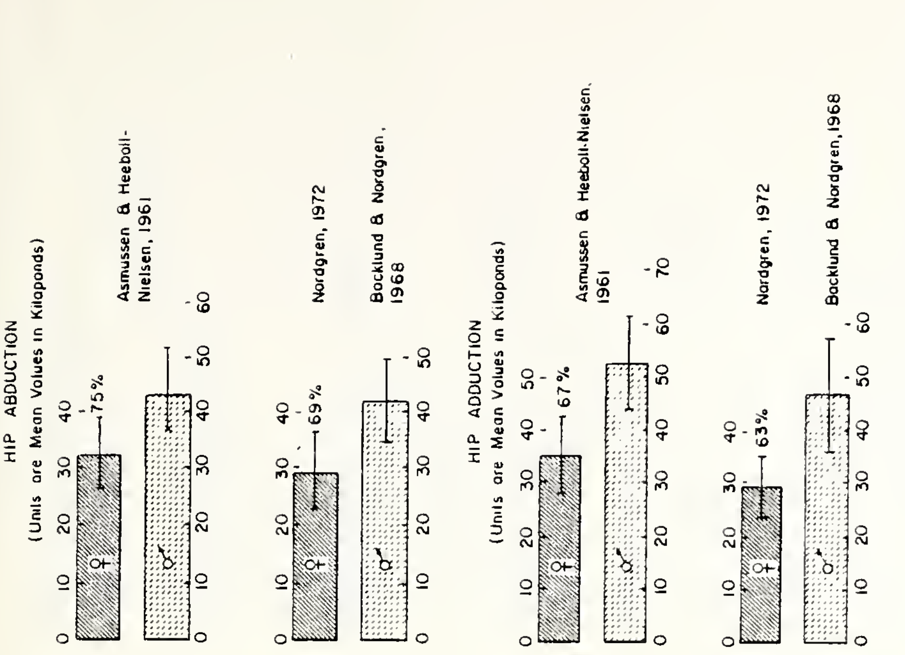
Female/male strength comparison: upper extremities.

National Aeronautics and Space Administration (NASA), Anthropometric Source Book, Volume I: Anthropometry for Engineers, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-40.

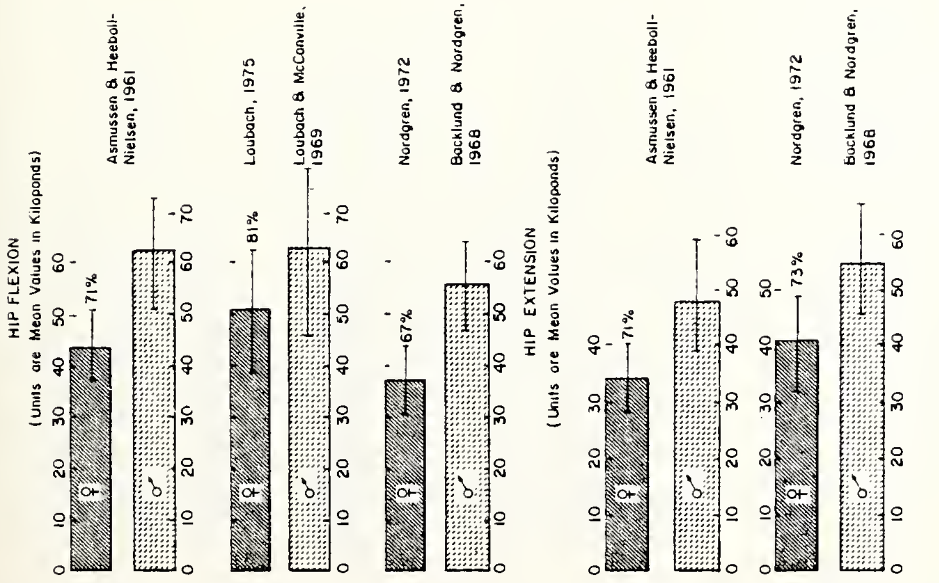


Female/male strength comparison: upper extremities.

National Aeronautics and Space Administration (NASA), *Anthropometric Source Book, Volume I: Anthropometry for Engineers*, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-41.



Female/male strength comparison: lower extremities.



Female/male strength comparison: lower extremities.

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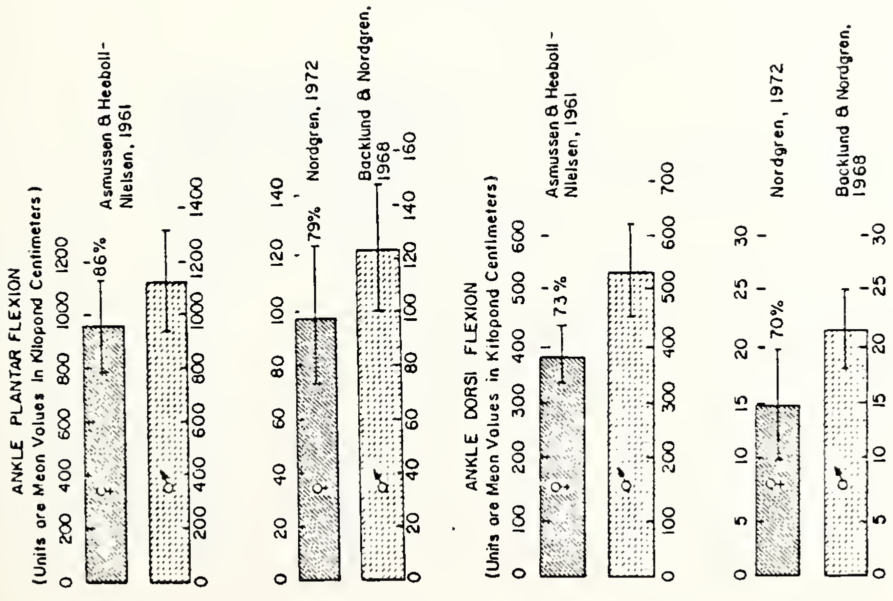
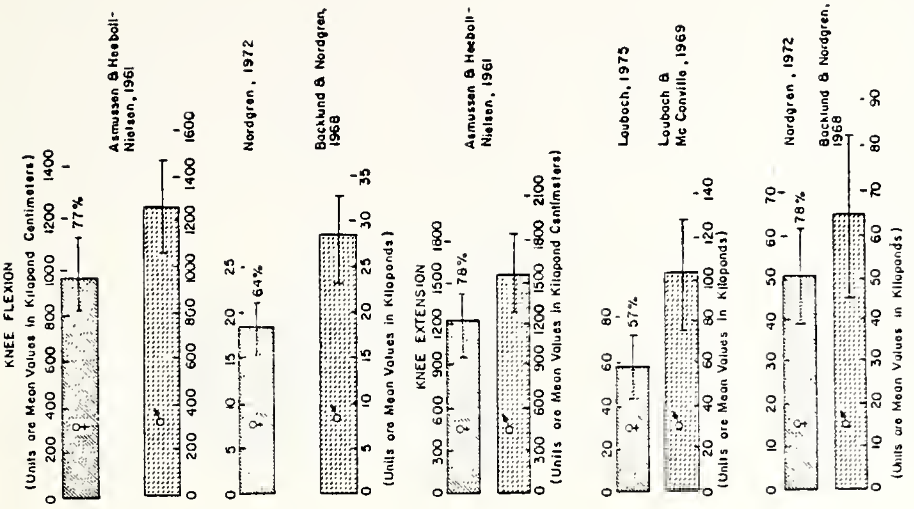


Female/male strength comparison: lower extremities.



Female/male strength comparison: lower extremities.

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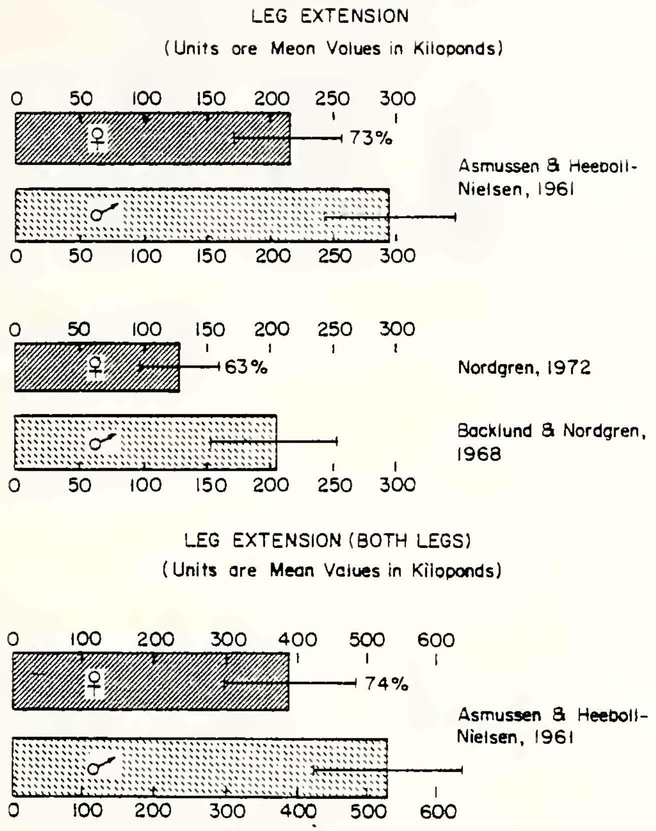
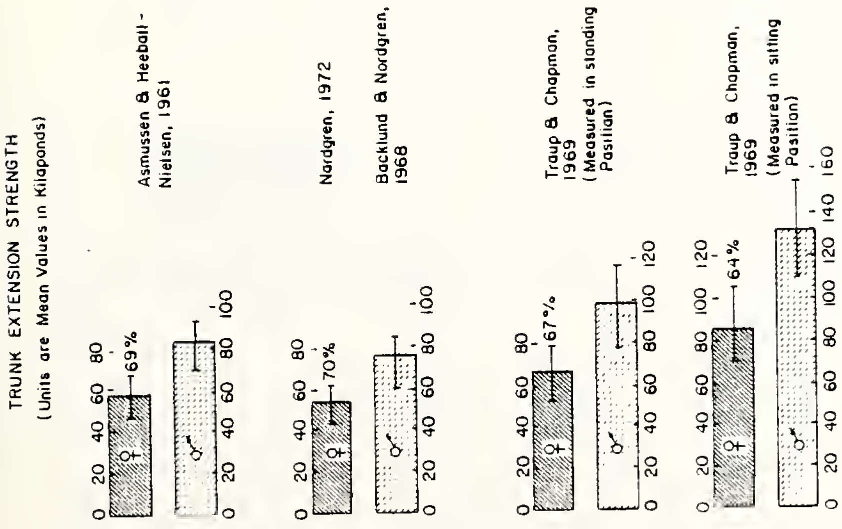
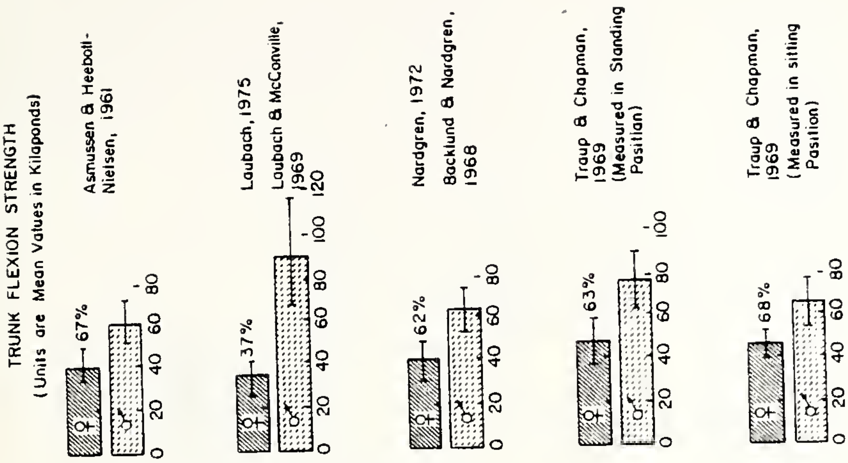


Female/male strength comparison: lower extremities.

National Aeronautics and Space Administration (NASA), Anthropometric Source Book, Volume I: Anthropometry for Engineers, Webb Associates, Yellow Springs, Ohio, 1978, p. VII-44.



Female/male strength comparison: trunk.



Female/male strength comparison: trunk.

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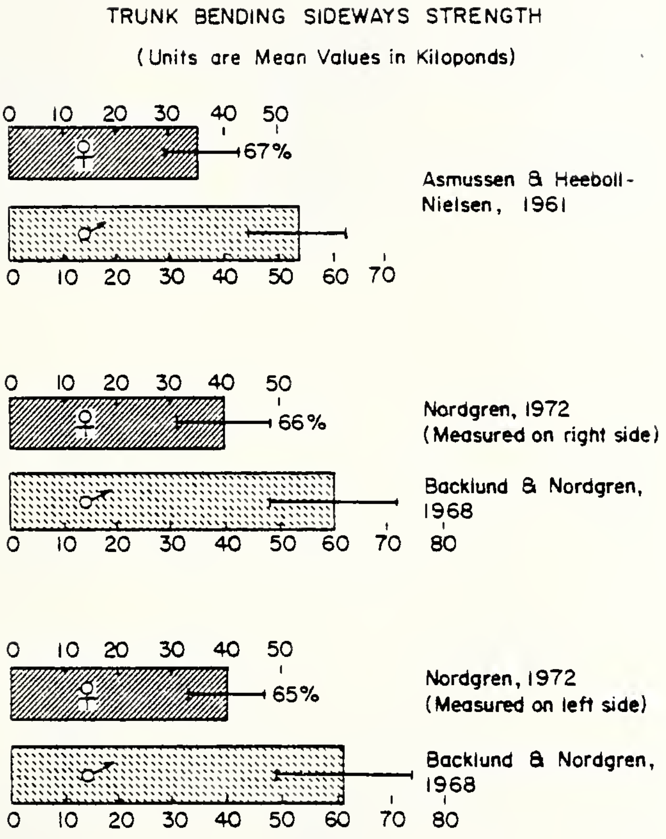

Female/male strength comparison: trunk.

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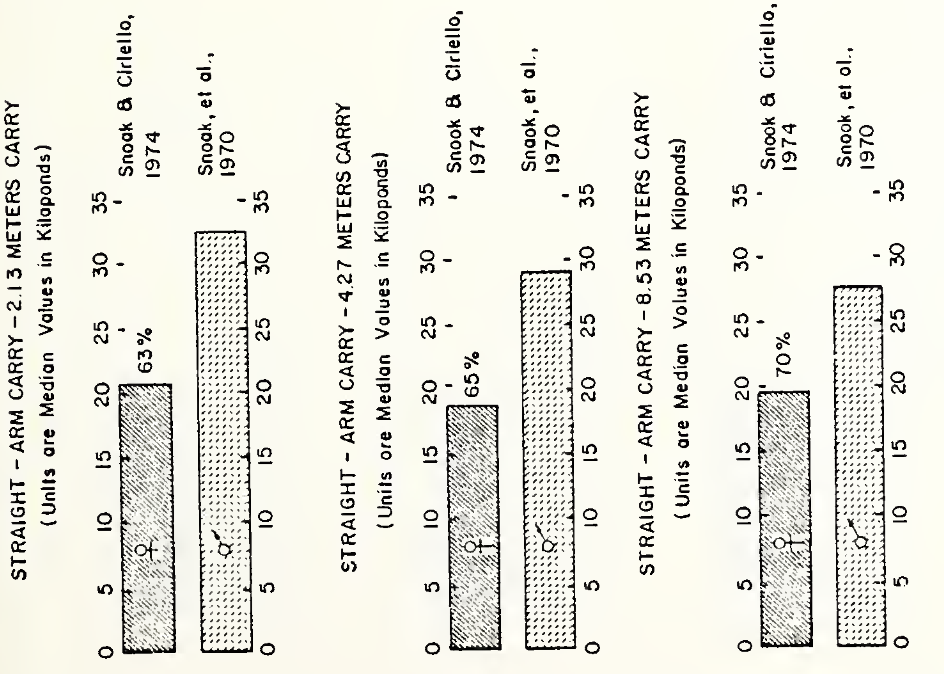
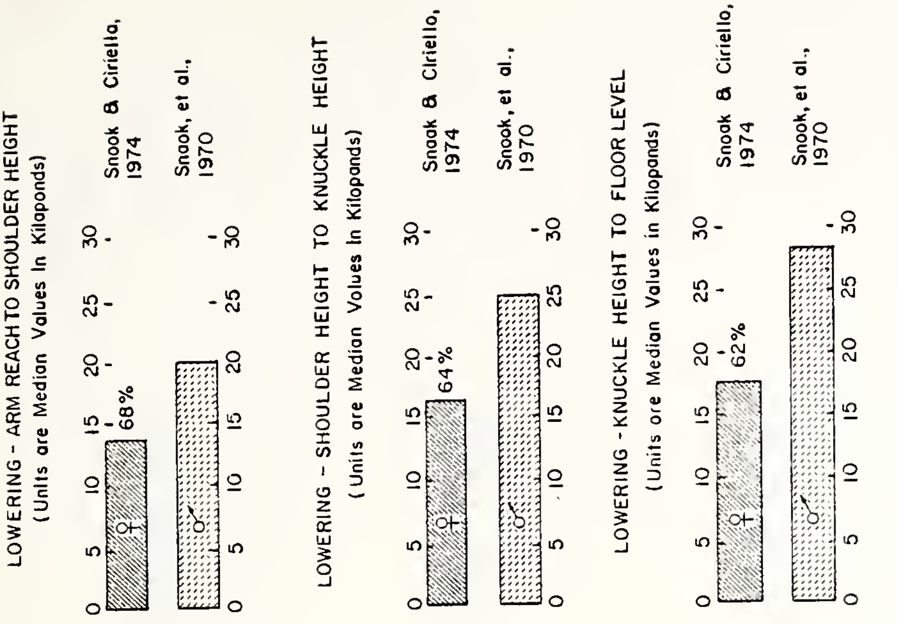


Female/male strength comparison: dynamic.



Female/male strength comparison: dynamic.

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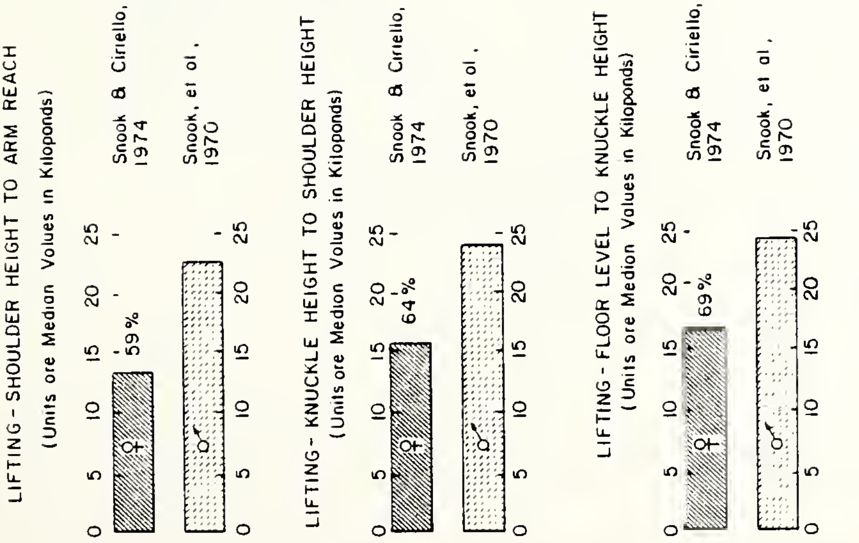
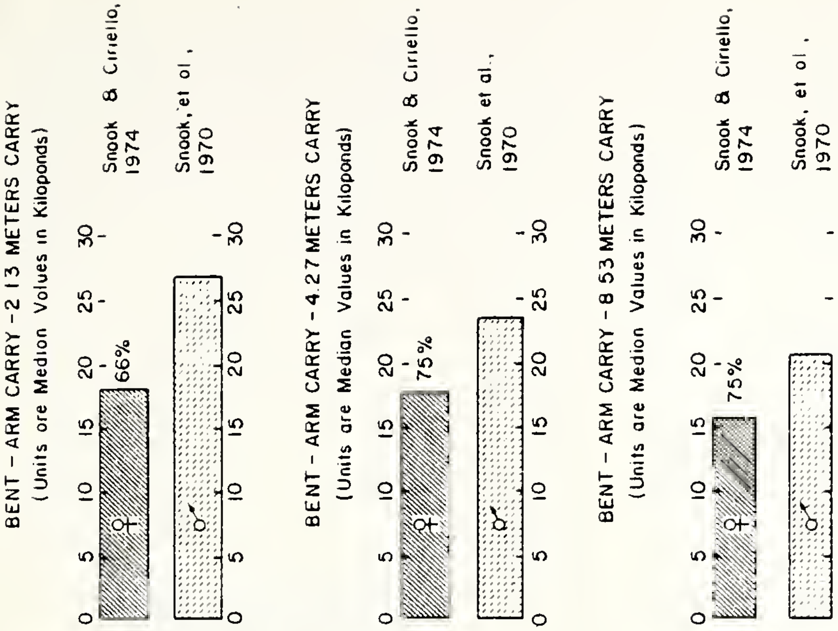


Female/male strength comparison: dynamic.



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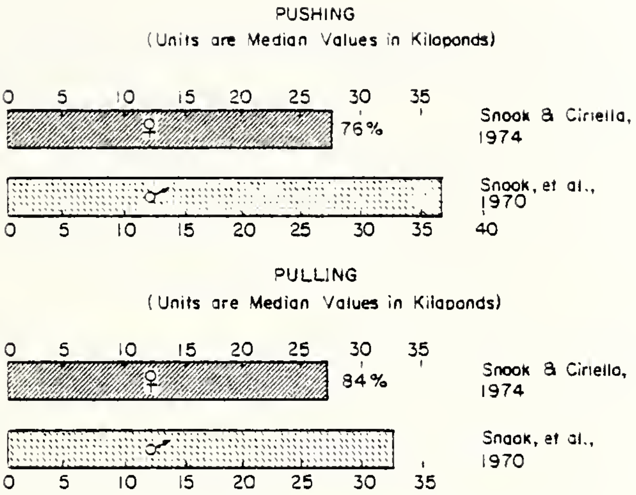

Female/male strength comparison: dynamic.

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